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GRAIN SIZE DISTRIBUTION OF SOME CLAYEY SANDSTONES: A COMPARISON OF GRAIN MOUNT, THIN SECTION AND SIEVING TECHNIQUES

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Grain Size Distribution of Some Clayey Sandstones: A Comparison of Grain Mount, Thin Section and Sieving Techniques", submitted by Shahid Noor Khan, M.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

I begin in the name of Allah

the beneficient the merciful

(Koran)

ABSTRACT

Grain size analyses of 18 sandstone samples of varied compositions (quartzose, subquartzose, arkose and lithic) and textures were performed by grain mount, thin section, and sieving techniques. The total distributions and the size-parameters derived from these distributions are compared for the three techniques.

The mean grain size obtained from the three techniques are closely correlated for both phi and millimeter data. The grain mount yields the highest value, the thin section an intermediate, and the sieving technique the lowest value of mean grain size. The observed differences between means, or median and mean grain size values, increase with changing grain size, thus a constant correction factor cannot be employed in translating the results of one technique to another. Statistically determined regression equations can be used to produce comparable results from the three techniques, but these are found to vary between samples and between rock types.

The thin section underestimates the mean sphericity of quartz grains in comparison to grain mount, and mean sphericity increases with size; also, there is a gradual increase in mean sphericity from lithic to quartzose sandstones.

Correlation of standard deviation, skewness, and kurtosis values is lower than those obtained for mean grain size, and in general show gradual fall in correlation towards higher moments. Comparison of total distributions show that grain

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INTRODUCTION

Determination of grain size-distribution of sediments is of significance to geologists and engineers. The engineer's interests stem from the practical utilization of sediments in the fields of soil mechanics, hydraulic engineering, petroleum engineering, etc. Sedimentologists have attempted to make use of grain size-distributions in reconstructing geological environments of deposition and distribution patterns, in particular in determining the environmental significance of various grain size parameters.

Size-distributions of clastic sediments can be measured in a number of ways, including sieving, measurement in thin section, measurement in loose grain mount, and various types of sedimentation and elutriation techniques. Each of these methods gives a different comparative measure of size and is based upon certain assumptions.

The concept of grain "size" is related to volume. However, the volumes of sand-size particles are difficult to measure directly, so that the "size" of such particles must be expressed in some other manner; for example, as a linear measurement of a unique axis, allowing an approximation to grain volume. In the three techniques of sieving, thin section, and loose grain mount, size is expressed as linear measurements, whereas in sedimentation techniques the size measure is some property more directly related to grain volume. Generally, settling velocity measurements of particles are reduced to hydraulically equivalent diameters by applying

Stoke's Law. Thus, in practice, grain size measurements require the acceptance of operational definitions of particle size that are only partly related to true grain volume.

Most size-distributions of sand-size sediments are determined by a combination of sieving and sedimentation techniques. The sieving technique is rapid and simple, and yields reproducable results if applied to unconsolidated or easily disaggregated material. The interpretation of the results obtained from combined sieving and sedimentation techniques assumes:

1. the sediment or rock can be broken into its original component particles or "grains";
2. the grains are of similar shape (preferably spherical);
3. the sizes and shapes of the particles in the rock mass have not been perceptibly altered subsequent to deposition (that is during diagenesis) through (a) formation of overgrowths (grain enlargements); (b) breakdown of grains through alteration (grain diminution), and (c) addition of cements.

Suffice it to say, most of the published literature dealing with grain size analysis concerns unconsolidated sediments (Recent or Pleistocene) or easily disaggregated "friable" rocks of older ages; few attempts have been made to systematically examine the conventional grain size parameters of well-cemented (indurated) rocks of older ages by sieving-sedimentation techniques, due to the failure of these materials to satisfy assumptions 1 and 3 above.

Thin section and loose grain mount techniques provide

alternate procedures for measurement of grain size in clastic sediments. In the former, the generally accepted procedure is to measure the longest axis (a-axes), restricting the counting to quartz grains only. Measurements are made either directly, by use of a micrometer eyepiece during observation of the thin section under the microscope, or on the projected image of the grain or on photographs of the grains. Loose grain mount measurements are obtained in the same way.

The main objections to size measurements obtained from these techniques are:

1. thin section measurements do not yield "true" grain size values because the maximum dimensions (a-axes) of most grains do not lie in the plane of the section;
2. there is a size cut-off in the fine range (fine to medium silt) beyond which individual particle boundaries are not easily resolved in thin sections of conventional thickness;
3. the size of the quartz grains may not have remained unchanged since the time of deposition of the sediments.

The advantages of thin section and loose grain mount techniques are:

1. the number frequency data obtained from thin section and loose grain mount techniques are more suitable for statistical analysis than weight percentage data;
2. measurements can be confined to one constituent, such as quartz grains, yielding a homogenous set of data more amenable to environmental analysis (Griffiths,

1967);

3. diagenetic effects can in part at least be recognized (e.g., clay cement) and excluded from the analysis;
4. disaggregation problems are eliminated in thin sections and more easily overcome in loose grain mounts;
5. in loose grain mounts the true long axes can be measured;

Therefore, the objectives of this study are:

1. to determine and compare values of the various size-sorting parameters obtained by the three techniques (sieve-sedimentation, thin section, loose grain mount) from sandstones of variable composition and texture; and
2. to find the interrelationships between the size-sorting parameters.

PREVIOUS INVESTIGATIONS

A review of the literature on size analysis shows that a majority of previous workers have depended largely on sieve size-distributions for grain size studies, and have attempted to correlate thin section or loose grain mount size-distributions with the sieving equivalents on the basis of either a theoretical or an empirical approach.

Krumbein (1935) adopted the theoretical approach, assuming a random distribution of spherical grains for correcting the moments of thin section size-distributions to obtain those for loose grains. His method does not give the total distribution and can be applied only if the measurements are grouped into equal arithmetic class intervals. Greenman (1951) extended Krumbein's work and developed a correction for random thin section effects by reconstructing the original total logarithmic distribution. However, as demonstrated by Friedman (1958), Greenman's technique increases the discrepancy between results of thin section and sieve analyses. Pelto (1952) extended Greenman's work by including corrections for random and systematic errors, and concluded that more particles must be counted in thin section in comparison to a grain mount to achieve the required precision in results. Roethlisberger (1955) proposed a graphical procedure of transforming chord measurements into a representation of grain size-distribution. Packham (1955) proposed using the intermediate diameter (b-axes) of grains in thin section to obtain a correlation with corresponding sieve size-distribu-

tions. His corrected thin section size-distribution is shifted towards the coarser size classes and falls between the observed thin section and sieve size-distributions. Sahu (1964, 1965) on the basis of a theoretical approach also suggested the use of the intermediate diameter (b-axes) for correlating the thin section size-distribution with its sieving equivalent. The intermediate diameter showed minimum variation with differing shape and roundness values of the grains. Sahu (1966, 1968) also developed a theoretical basis for transorming number frequencies to weight frequencies to bring thin section size-distributions into aggreement with sieve size-distributions. Dixon (1966) made minor amendments to Sahu's "theory of transformation".

Earlier, Hagerman (1924), Bruckner (1935), Munzer and Schneiderhohn (1935), Vaugnat (1949), and Chayes (1950, 1951), had also considered the relationship between sieve and thin section techniques for size analysis on the basis of theoretical corrections.

The theoretical approaches cited in the preceding paragraphs require certain assumptions:

1. grains are spheres or ellipsoids with high and nearly constant sphericity;
2. the spheres (grains) are randomly distributed, and are continuously graded;
3. the nominal sectional diameter is defined as the diameter of a circle having the same area as the maximum grain section (horizontal intercept);
4. all grains in a class interval are of the same size.

Rosenfeld, Jacobson, and Ferm (1953 p. 114-126) made a detailed comparison of the results of thin section and sieving techniques, and listed fifteen factors which accounted for the discrepancies between the results of the two procedures. They compared the two types of distributions and measured the differences between them, concluding that...

> .."analytically derived correction factors for sectioning and for weight to number frequency fail to bring the results of the two techniques into agreement."...(p.114).

However, they found that empirically determined conversions with statistically determined confidence limits could be applied to similar rock types. Following the empirical approach, Friedman (1958, p. 405-416) showed that a linear relationship exists between quartile size measures from the sieving and thin section techniques for quartz-rich sandstones and that...

> .."the cumulative frequency curves for sieve size-distributions can be derived from thin section data using graphical quartile measures with the aid of an overall regression or correlation graph."...(p. 416)

In 1962, Friedman extended this approach to moment measures. His quartile equation converting thin section moments to observed sieving quartiles is valid only for mean grain size values.

Smith (1966, p. 842-432) made a direct empirical comparison between the results of the loose grain mount and thin section techniques. He found that the thin section technique underestimates true grain size by a constant amount, "true"

grain size being represented by grain mount measurements. He found that 43 percent of the variability is common when the a-axes (maximum apparent dimension) of quartz grains in thin section are compared with the a-axes of quartz grains in grain mounts; the remaining 57 percent is attributed to differences in the two techniques due to grain fabric.

SAMPLING AND ANALYTICAL PROCEDURES

Source of Samples

The 18 samples for this study were provided by Dr. G.B. Mellon, Research Council of Alberta, supervisor of the project. The samples comprise marine and non-marine quartzites, lithic sandstones, and arkose. The samples were randomly selected from rock units ranging in age from Pennsylvanian to Pleistocene, from scattered localities in Alberta, northeastern British Columbia, and Colorado. Details regarding the locations and stratigraphy of the samples are given in Table 1.

Conceptual Definitions

According to Griffiths (1959), an aggregate of particles, or a rock, is defined by the combined properties of its elements or minerals and the characteristics of their association. Mineral composition, expressed as relative abundances of types of particles, and the characteristic properties of size and shape, form the fundamental properties of the particles themselves. Measures of orientation and packing (fabric) define the position and order of arrangement of these elements. Once these properties are known, an aggregate or rock can be defined in the form of an equation (Griffiths, 1959):

$$P = f(m, s, sh, o, p)$$

where P = an index characterising the population

m = mineral composition

s = particle size of mineral fragments

sh = particle shape

o = orientation .
. grain fabric
p = packing .

There are other properties such as porosity, permeability, and hardness, etc., which can be used to characterize an aggregate. These are called behavorial or derived properties, and variation in each is dependent on the above-listed five fundamental properties of the aggregate.

The fundamental and derived properties are closely interrelated. For example, measures of grain size obtained from a particular technique are confounded by the "interaction" with other rock properties, in that variation in size measurements may be affected materially by variation in other properties. As the purpose of this study is to compare the results of grain size analyses performed by the sieve-sedimentation, thin section, and grain mount techniques, the results of grain size measurements are discussed below in the light of Griffiths's fundamental equation as applicable to the three techniques.

In sieving plus pipette sedimentation techniques, rock samples under ideal conditions are disaggregated into their individual particles, thereby eliminating the effects of orientation and packing. Griffiths (op.cit.) proposed the following equation for sieve analysis:

$$Ps_1 = f(m,s,sh) \qquad (1)$$

The sieve technique encompasses a polymineralic and polycomponent system and the size measure Ps_1 is a function of three variables, namely, composition, size, and shape. These vari-

ables are interdependent and their interaction materially contributes to the size measure obtained.

In the thin section technique, composition is kept constant by restricting measurements to quartz grains; thus, the equation is reduced to:

$$Ps_2 = f(s,sh,o,p) \qquad (2)$$

Consequently, size measure Ps_2 varies with shape, orientation, and packing, and a constant correction factor is not possible.

A comparison of size measures Ps_1 and Ps_2 can be expressed in the following manner:

$$f_1(m,s,sh) = f_2(s,sh,o,p) \qquad (3)$$

The differences between the two techniques depend upon mineral composition, orientation, and packing. However, size measure Ps_1 is only affected by variation in the composition of grains (Rosenfeld et.al., 1953; Friedman, 1958).

For grain mount analysis, the sample is disaggregated to obtain the original clastic particles, which process eliminates the combined effect of orientation and packing on size measurements. The equation for grain mount size measurements is given by Griffiths (1959) as follows:

$$Ps_3 = f(s,sh) \qquad (4)$$

as composition is held constant if measurements are confined to grains of quartz. Thus, this technique provides the "purest" measure of grain size, the results being affected only be variation in grain shape.

Laboratory Techniques

Size analysis by sieving plus pipette sedimentation techniques

The grain size-distributions of the eighteen samples listed in Table 1 were obtained by conventional sieving and pipette sedimentation techniques. Three types of sandstones were used:

(a) friable sandstones,

(b) well-indurated calcareous sandstones, and

(c) oil-impregnated sandstones.

The friable sandstones were disaggregated by hand rubbing or by gentle crushing with a wooden roller on a glass plate. The more indurated samples were passed through a jaw crusher and the resulting fragments disaggregated in a porcelain mortar using a rubber pestle. Samples with calcareous or ferruginous cement were treated with hot hydrochloric acid. Samples with bituminous material were washed in acetone and benzene.

The samples were examined for aggregates under the binocular microscope and soaked in distilled water for 24 hours before being wet-sieved, dried, and weighed. The coarser than 230 mesh fraction was sieved at 0.25 phi intervals for 15 minutes on a Tyler "Ro-Tap" machine and each sieve fraction was weighed. Separate sieve fractions were examined for the presence of aggregates under the microscope, and the sieves themselves were checked for oversize and undersize areas under the binocular microscope.

The finer than 230 mesh (silt and clay) fraction was utilized for the pipette analysis. Five grams of calgon

powder (sodium hexametaphosphate) was added as a disperseant in 1000 millilitres of distilled water.

In the subsequent sections of the thesis, the term "sieving" has been used for the combined sieving and pipette sedimentation techniques.

Size analysis by the thin section technique

A point-counting procedure involving a mechanical stage with an attached point-counter device (Glagolev, 1933; Chayes, 1949) was used for random selection of grains. The grains were selected by traversing each thin section perpendicular to the inferred bedding direction. Ten equi-spaced traverses were carried out on each section, and 20 quartz grains were measured on each traverse, for a total of 200 grains per sample. For each grain, the maximum observable dimension (a-axis) was measured with the aid of a micrometer eyepiece. The maximum dimension perpendicular to the a-axis (b-axis) also was measured, from which the grain "shape" (b/a) values were determined. Thus, thin section quartz grain size can be expressed in terms of the dimension of the a-axes or b-axes in millimeters, and the shape as the "dimensionless" ratio of the two axes.

Size analysis by the loose grain mount technique

Portions of individual pieces of sandstones which had earlier provided material for the sieving analysis and thin section were gently disaggregated into detrital grains and soaked in distilled water. Clay cements and coatings on the grains were removed by hand rubbing and decantation. Grains with calcareous and ferruginous coatings were treated with hot hydrochloric acid. The disaggregation procedures adopted for the sieving and loose grain mount techniques are the same except that these differ somewhat in the degree of disaggregation.

Loose grains so obtained were mounted in Canada balsam on glass slides. The grains lie approximately in the position of maximum stability, that is with the a- and b-axes in the plane of the slide, and c-(short) axis perpendicular to the slide (Hulbe, 1957; Griffiths, 1959a, 1959b, 1967; McIntyre, 1961; and Rogers, 1965).

Both the a- and b-axis dimensions, as defined earlier, and the shape values were obtained by measuring 200 randomly selected grains in each slide.

Data Processing

The raw data from the three techniques provided 54 sets (a,b,b/a values for 18 samples) of analytical observations. These contain 18 sets of weight-frequency observations and 36 sets of number-frequency observations which are given in Appendix D. Parameters for the weight-frequency data (sieve-pipette analyses) were obtained by means of graphic procedures

that yield results in millimeters or phi units. APL-360 programs were used to calculate the corresponding moment parameters for the number frequency data. Also, the APL-360 program was utilized to run reggresion and correlation analyses of the values obtained from the three techniques. Details regarding graphic and moment statistics and computer programs are given in Appendix A and C.

MINERAL COMPOSITION AND CLASSIFICATION

Mineral Composition

Krynine (1948), on the basis of relative size and relative position in space of the constituents, described the "textural" elements of clastic sedimentary rocks as grains, matrix, and cement. Grains are basic elements of texture and are the transported (and abraded) particles that form the clastic framework of a rock. Matrix consists of "intergranular" particles which because of small size relative to the larger grains fill the open spaces within the framework of grains. Cements are chemically precipitated minerals which infilterate the rocks after deposition of the "grains" and "matrix". Cements have a "crystalline" rather than a "granular" texture.

Interpretation of the results of any size analysis must therefore take into account the origin of the constituents of the rock in terms of their relative position, time and mode of formation.

For this study, the main mineral constituents of the rocks were grouped into four major classes shown in Table 2: grains, matrix, cements, and constituents of uncertain origin and accessory minerals. Krynine's (1948) fifth major class of "pores" was neglected as most of the samples were virtually non-porous. The four major classes in turn were grouped into subclasses, the proportions of which were determined by point-counting thin sections from each of the 18 sandstones examined. The counts were made by traversing each thin sec-

tion perpendicular to the bedding; 20 "points" were obtained from each of the 10 equi-spaced traverses for each thin section, yielding a total of 200 "points" per sample. The results (converted to percentage) are shown in Table 2.

Description of the mineral constituents

Grains - Grains are comprised of quartz and quartzite, chert, feldspar, micas, rock fragments and clastic carbonates.

Quartz and quartzite - Grains of quartz are common in all the rock types studied. These are clear to cloudy, and carry inclusions of bubbles, mica, zircon and apatite. Metaquartzites, polycrystalline quartz, and a few monocrystalline grains show undulose and regional extinction. Authigenic overgrowth of silica is sometimes present.

Chert - The chert grains are colorless to brownish and subangular to subrounded. The cherty cement in Sample 17 is of secondary origin.

Feldspars - Clear to cloudy, altered and unaltered, (twinned and untwinned) plagioclase, orthoclase, and microcline grains are common in all samples. Plagioclase shows alteration to sericite, chlorite and epidote and partial or complete replacement by calcite.

Mica - Detrital flakes of biotite and chlorite with occasional muscovite occur in most samples. Flakes have been bent during compaction. In some cases, biotite has altered to chlorite.

Rock fragments - Dark to brownish yellow stained fragments of andesite and glassy volcanic rocks, schists, phyllites,

slates, argillaceous rocks and clastic carbonates are common in the lithic sandstones. The metamorphic and sedimentary rock fragments are squeezed between the quartz grains and altered to varying degrees. Chloritization, glauconitization and hematization are the main diagenetic changes. Rounded hematitic and limonitized grains are present in non-marine sandstones. These were probably originally siderite grains which have since been oxidized.

Matrix - Brownish irregularly shaped argillaceous material with silt-size grains of quartz forms the matrix. It is common in several lithic sandstone samples, where it forms an almost continuous groundmass with detrital grains in clusters strewn through it. The amount of matrix decreases with increase in size and relative abundance of quartz grains until it is restricted to small, isolated patches.

Cement - Cement has been subdivided into smaller subclasses of siliceous, calcitic, ferruginous, clayey and kaolinitic cements. Hematite and limonite comprise the ferruginous cement whereas clayey cement includes illite, chlorite, montmorillonite and zeolites. Cement is common in most of the samples and is present as a thin film around grains and as porespace filling. There may also be partial to complete replacement of detrital grains by cement.

Uncertain and accessory minerals - Opaque materials, probably organic, constitute 0.5 to as much as 1.5 percent of several samples. The grains appear dull black in reflected light. Concretions of pyrite showing brassy lustre in reflected light are common in sample 15. Accessory minerals including

zircon, garnet, kyanite, epidote, tourmaline, sphene and hematite are rare constituents of the sandstones.

Classification

According to Krynine (1948) a rock has two basic fundamental properties-composition and texture. The texture of a clastic sedimentary rock is dependent upon the relationship between its major mineral constituents, which is a function of the mode of formation of the rock. As the present study is concerned with the size analysis of detrital rocks, it is important that the relationship between composition and texture be fully understood. It has been explained in the sections on "Analytical Procedure and Analysis of Grain Size Data" that grain size is influenced by variation in composition. Also, the shape of the grains, which is dependent on composition, influences the grain size. As such, a compositional ternary diagram (Figure 1) is proposed to explain the influence of composition on textural elements and ultimately on the size analysis. It is called an MRC-diagram and is based on the following factors:

1. Composition of the major mineral constituents;
2. Textural elements: grains, matrix and cement;
3. Mineralogical maturity;
4. Provenance and weathering;
5. Sorting; and
6. Detrital versus chemical fraction.

In this diagram, the M-pole represents the pole of monomineralic grains that will stand up to disaggregation.

Quartz and chert, because of their relative stability, are grouped along with stable heavy minerals (zircon, tourmaline etc.) at the M-pole. The R- and C- poles represent the unstable material which may break up on disaggregation. Rock fragments, feldspars, micas and matrix are grouped at the R-pole. The chemical cement, including authigenic silica, calcium carbonate, ferruginous cements (probably oxidized siderite) and micromicaceous clays of the chlorite and kaolinite series are grouped at the C-pole.

In the subsequent sections of the thesis, the terms arkose (quartz, 50% or less; rock fragments, 12% or less; and feldspars, 12% or more), lithic sandstones (quartz, 50% or less; rock fragments 12% or more), subquartzose sandstones (quartz, 50 to 75%) and quartzose sandstones (quartz 75 to 100%) have been used to facilitate comparison of results with published work and for ease of reference.

Effect of Composition on Grain Size Measurements and Engineering Properties of Sandstones

There is a correlation between composition of the constituents of a clastic sedimentary rock and grain size. The stable primary detrital constituents such as quartz and chert are usually of sand size or coarser, where as unstable constituents such as feldspars and various types of rock fragments may disintegrate to produce finer size material.

The eighteen studied sandstones can be broadly placed

into four compositional groups, namely, arkose, lithic sandstone, subquartzose sandstone and quartzose sandstone. These sandstones have six types of dominant cements as shown in Figure 1. The eight sandstones containing clays plus calcium carbonate or clays alone as dominant cement are lithic sandstones, with the exception of one quartzose sandstone (17). These lithic sandstones carry appreciable percentages of clayey material (Figure 2) which may greatly influence size analysis. The cumulative size-frequency curves of these sandstones show long tails of fines (below sand size) which affect the values of means, medians, and other size-parameters, and show these sandstones to be poorly sorted, excepting the quartzose sandstone (17) which is moderately well sorted. However, the standard deviation values calculated from the number-frequency data show all these sandstones to be moderately well-sorted to well sorted, indicating that the clays (mainly authigenic) affecting the size analyses (determined by pipette sedimentation) are responsible for the break in the cumulative curves at 4 phi size. These cumulative curves suggest composite size-distributions. Thus, the cumulative curves are notably skewed and may or may not reflect the original environmental conditions of deposition. The subquartzose and quartzose sandstones with dominant stable mineral constituents (quartz and chert) and varied types of cements are moderately well sorted to well sorted, and have nearly log normal sieve size-distributions in the portions of the cumulative curves derived from sieving. The cumulative curves invariably show sharp breaks at the points (4 phi) where

sieve cumulative curves join the pipette cumulative curves, an effect of clayey cement (authigenic) which produces increased skewness towards the fines. However, skewness is more pronounced in lithic sandstones because of larger per= centage of fines and clays than in subquartzose and quartzose sandstones. The increased skewness values in subquartzose and quartzose sandstones(compared with standard deviation values) may give a wrong impression of their environmental depositional significance. Therefore, the grain size analysis is affected by variation in composition of the mineral constituents.

The compositional aspects of size analysis are also important to engineers for judging the behaviour of soils under working stresses. Normally, sandstones have maximum density with normal moisture content, and will be stable under stress at the surface. However, sandstones rich in clays and silt (lithic sandstones), and having an abnormal moisture content, become more sensitive and unstable when disturbed (have low liquid limit and low plasticity index). However, given the physical properties of clays the necessary calculations for adjustments can be made.

ANALYSIS OF GRAIN SIZE DATA

Size frequency Distributions

Frequency histograms showing the size-distributions of a-axes measurements from thin section and loose grain mount analyses, and weight-percentage size distributions from sieve analyses in phi units are shown in Figure 3 for the eighteen sandstone samples. The theoretical normal frequency distributions also have been calculated for thin section and loose grain mount data. The histograms show a general leftward shift of modal class towards the lower phi values (larger size) from sieve to thin section to grain mount. The frequency distributions are more unimodal, nearly symmetrical, mesokurtic to very leptokurtic in quartzose and subquartzose sandstones; and unimodal to polymodal, unsymmetrical, platykurtic to extremely leptokurtic in lithic sandstones and arkose.

A comparison of the thin section and loose grain mount size frequency distributions of four sandstones plotted on a phi scale, and with the same distributions plotted on a millimeter scale is shown in Figure 4. The data indicates that the size frequency distributions of lithic (Figure 4a,b,c,d), subquartzose (Figure 4e,f,g,h) and quartzose sandstone (Figure 4i,j,k,l) are either symmetrical or skewed towards finer sizes when drawn in phi units in both thin section and grain mount, and become asymmetrical and highly skewed towards coarser sizes when plotted with a millimeter scale; excepting the frequency distribution of subquartzose sandstone (Figure

4f) which shows a fairly normal frequency curve. The size frequency distributions of the arkose in thin section and grain mount show polymodal behaviour when plotted in phi units (Figure 4 m&o). However, the distribution with millimeter scale is asymmetrical and bimodal in grain mount, and polymodal in thin section.

Comparison of Means and Medians

The mean and median have been selected as the best measures of central tendency, that is the "average" size of a distribution. The median is most suitable for open-ended distributions and the mean for closed distributions.

The means of quartz grain a-axes in thin sections and loose grain mounts, and the medians of total samples from sieve analyses vary from sample to sample. In general, thin section analyses yield coarser size values than sieve analyses, and grain mount analyses yield coarser size values than thin section analyses. The average median value from sieve analyses of eighteen samples is 2.83 phi, and the average mean values from thin section and grain mount analyses are 2.53 and 2.29 phi, respectively. Thus, the discrepancy between values is greater between sieve and thin section techniques (0.30 phi) than between thin section and grain mount techniques (0.24 phi).

Differences between median and mean size values for the three techniques are plotted in Figure 5 against mean grain mount size. The three diagrams show a wide scattering of

points; however, an indication of increase in difference with higher phi sizes is noted in Figures 5a and 5b. The scatter diagrams 5a and 5b show a compositional grouping by rock types similar to the patterns observed by Rosenfeld, et.al. (1953, p. 125) in their study of grain size techniques. The fields of arkose, lithic sandstones and subquartzose plus quartzose sandstones are clearly demarcated. Thus, it can be said that the differences in mean and median or mean sizes are related to the size measures obtained from the three techniques, and are attributed to the differences between the techniques. These and other relationships between median and mean size values are discussed below.

Regression Analysis

The interrelationships among the three sets of mean and median grain size analyses for the eighteen samples were determined by linear regression analysis. The analyses were done for both phi and millimeter data, and the two scatter diagrams for each of the three sets of values are shown in Figure 6.

A. - Thin section versus loose grain mount values

The relationship between thin section mean a-axes and grain mount mean a-axes measurements are given by linear regression equations of the form:

$$y = a + bx \qquad (5)$$

where y,x are the mean values determined from the two techniques in phi or millimeter units;

and

a = intercept on y-axis

b = slope of the regression line.

The equations determined by least squares procedure for the two sets of data are:

$$y = 0.218 + 1.008x \quad \text{(phi units)} \tag{6}$$

and

$$y = \bar{0}.0456 + 1.14x \quad \text{(mm units)} \tag{7}$$

where x = mean a-axes, loose grain mount technique; and

y = mean a-axes, thin section technique.

If there are no differences between the results obtained by the two techniques, then the regression coefficient (b) should equal 1 and the intercept (a) should equal 0 (Taro, 1967, p. 410-412). For the phi data, b is not significantly different from unity as determined by the t-test (Snedecor, 1946, p. 119), and the intercept (a) is not significantly differenct from 0 at the 0.050 level (actually significant at the 0.25 level). The departure of residual variance (0.2066) from 0, however, indicates that the two techniques are different (Taro, 1967, p. 391-401).

For the millimeter data, regression coefficient (b) and a-intercept are significantly different at the 0.005 and 0.01 levels, respectively (Table 9). This indicates that the thin section underestimates the size in comparison to the grain mount by a constant ($\bar{0}$.0456mm), and that the difference increases with decrease in size and decreases with increase in size.

The correlation coefficients (r) for the two equations

are 0.83 and 0.99 for phi and millimeter data, respectively (Table 9). Thus, about 30 percent (r^2) of the variation in phi size measurements remains "unexplained" by the regression of the two techniques, whereas only 2 percent of the variation in millimeter size measurements cannot be attributed to the regression.

The effect of mineral composition on differences in grain size analyses obtained by the two techniques is not obvious from the scatter of points in Figure 6a. The quartzose and subquartzose sandstones (derived quartzites, subquartzites), rocks with little or no clayey cement, show minimum deviations from the regression line, whereas the lithic sandstones with a high "matrix" content (detrital and authigenic clays) show somewhat higher deviations, although these are not consistent in one "direction". The lack of any clear-cut trend here might be expected on theoretical grounds, as the finely crystalline silty and clayey constituents of the rocks are not directly accounted for in determining grain size by either procedure.

B. - Loose grain mount versus sieve values

Scatter diagrams showing the relationships between grain mount mean a-axes and sieve median measurements are shown in figure 6c and 6d. The corresponding equations for the two sets of data in phi and millimeter units are:

$$y = 0.999 + 0.8x \quad \text{(phi units)} \qquad (8)$$

and

$$y = 0.093 + 0.245x \quad \text{(mm units)} \qquad (9)$$

where y = median, sieve technique, and

x = mean a-axes, loose grain mount technique.

The regression coefficient (b) and intercept (a) are significantly different from unity and zero, respectively at the 0.10 and .005 levels in the case of phi data, and are significant at the 0.0005 and 0.05 levels, respectively for the millimeter data. The sieve analyses underestimate the grain size in comparison to the loose grain mount technique, and thus provide a higher phi or lower millimeter estimate of the average grain size of most sandstones (17 of 18 sandstones described here).

The correlation coefficients (r) for the two equations are 0.83 for both phi and millimeter data. Thus, 31 percent (r^2) of the variation in phi and millimeter size measurements remains "unattributed" by the regression of the two techniques (Talbe 9).

The effect of composition on size analysis by the above two techniques is not obvious from the scatter diagram 6c. All the quartzose and subquartzose sandstones lie on or close to the regression line in comparison to the lithic sandstones which are widely scattered both above and below the line. The observed sieve median phi size values are higher (lower in mm) in comparison to grain mount mean a-axes values, indicating shift of sieve median values towards higher phi sizes, an effect of silt size fraction and cement. The shift in sieve median phi values is more pronounced in the case of three lithic sandstones (4,12,13) which are rich in matrix and clayey cement.

C. - Sieve versus thin section values

The scatter diagrams showing the relationships of median

size values obtained by sieve analyses and thin section mean a-axes size values for the eighteen sandstones are given in Figure 6e and 6f for phi and millimeter data, respectively.

$$y = \bar{0}.7759 + 1.66x \qquad \text{(phi units)} \tag{10}$$

and

$$y = \bar{0}.2578 + 3.257x \qquad \text{(mm units)} \tag{11}$$

where y = mean a-axes, thin section technique and

x = median, sieve analyses.

The regression coefficient(b) and y-axes intercept (a) are significantly different from unity and zero at the 0.10 and 0.025 levels, respectively, for the phi data, and at 0.010 level for the millimeter data.

The correlation coefficients(r) for the two equations are 0.92 and 0.83 for phi and millimeter data, respectively. Thus, about 15 and 31 percent (r^2) of the variation cannot be explained in phi and millimeter size measurements, respectively, by the regression analysis. The thin section analyses yield lower phi or higher millimeter size values on the average than the sieve analyses, and thus provide a higher estimate of the average grain size of most of the sandstones (14 of the 18 sandstones described here).

If grouped by composition, 7 of the 9 subquartzose and quartzose sandstones fall above the regression line in Figure 6e, and 6 of the 8 lithic sandstones and the single arkose fall below the regression line. That is, the quartzose rocks yield slightly lower sieve median phi values than expected from the regression analysis of the entire suite of sandstones, and the lithic sandstones somewhat higher values. This disposition of points on the scatter diagram indicates that composition is influencing the results of size analyses; presumably,

the fine silt and clay content of the lithic sandstones tends to shift the median size values determined by sieve analyses towards the finer sizes (higher phi size value), although the opposite effect is observed in two clay-rich samples (S. No. 6, 12).

Summary

Table 10 gives the observed mean grain mount a-axes size values in phi units for the eighteen sandstone samples, together with the observed and "corrected" equivalent mean and median size values determined from thin section and sieve analyses. From these and the regression analysis data, the following observations can be made with respect to the interrelationships of the mean size values determined by the three techniques.

1. The results obtained by the three techniques are highly correlated.
2. The grain mount technique yields the highest (i.e. the coarsest) estimate of "average" grain size, and the sieve technique the lowest estimate. Although tests of significance indicate that the slope (b) and intercept (a) for the regression equation involving grain mount and thin section results in phi values are not significantly different from unity and zero, respectively, a comparison of the sets of observed values from the two techniques in Table 10 indicates that the results are different. The residual variance sigma$(y-yc)^2/n-2=0)$ of y is also diff-

erent from zero(0.2066) and shows that the techniques are different.

3. The slope (b) of the regression lines indicating the linear relations among the results of the three techniques are significantly different from unity at the 0.005 level for the millimeter data and at 0.1 or greater level for the phi data (Table 9). This indicates that the observed differences between mean or median grain size values obtained from the three techniques change with changing grain size; thus, a constant correction factor cannot be employed in translating the results of one technique to another. The exception to this statement is found in the regression equation for phi values for grain mount and thin section analyses, in which (b) is not significantly different from unity. However, the very fact that the residual variance of y is different from zero(0.2066) suggests that the slope (b) is not exactly unity.

4. The effect of mineral composition on grain size analysis is uncertain owing to the small number of samples involved. However, plot of differences between median and mean (thin section) and median and mean (grain mount) against mean grain mount in Figures 5a and 5b suggest that composition has some effect on the results of sieve analyses, especially when compared with the results of thin section size analyses.

Sphericity

Sphericity is one of the components of grain "shape", and can be defined in terms of the three major axes of a grain the long or a-axis, intermediate or b-axis, and short or c-axis lying in planes perpendicular to one another. In thin sections, in which the observed grain outlines constitute random two-dimensional slices through irregularly shaped grains, only two mutually perpendicular axes can be observed, conventionally referred to as the long or a-axis and a b-axis which is the maximum dimension of a grain along a line drawn at right angles to the a-axis. In loose grain mounts it is assumed that the majority of grains rest in the plane containing the long a-axis and the intermediate b-axis, with the short c-axis at right angles to the plane of observation. Thus, a set of a- and b-axes measurements can be obtained from loose grains mounted on a flat surface and compared with corresponding sets of randomly selected a- and b-axes measurements obtained from thin sections.

The histograms based on number frequency data of b/a ratios in thin sections and loose grain mounts of eighteen sandstones are unimodal and quasi-symmetrical except that they are truncated at the upper limit of sphericity values (max. sphericity = 1). In general the grain mount modal values lie in the 0.70 to 0.80 range and the thin section values in the 0.60 to 0.70 range (Figure 7). Also, the truncation at the upper limit of sphericity values is more pronounced in grain mount than in thin section. Some differ-

ences also are apparent among the various rock types present, which are discussed below in more detail.

Comparison of Mean a- and b-axes Measurements

A. - Loose grain mount values

Scatter diagrams showing the relationships between mean a- and b-axes observed in loose grain mounts of eighteen sandstones are given in Figure 8 (a and b) for both phi and millimeter data. The diagrams show close positive linear relationships for the two sets of data, the corresponding regression equations being:

$$y = 0.0216 + 1.186x \qquad \text{(phi units)} \qquad (12)$$

and $$y = \bar{0}.0099 + 0.7879x \qquad \text{(mm units)} \qquad)13)$$

where y = mean, b-axes, and

x = mean, a-axes.

The regression coefficient (b) is significantly different from unity at the 0.050 level for phi and millimeter values, whereas the y-axis intercept (a) is significantly different from zero (at the 0.025 level) for the millimeter data and insignificant for the phi data. Thus, it can be said that sphericity varies directly with size in the case of millimeter values; the grains become more spherical with increase in size and more elongated with decrease in size. The movement of fine size particles is by suspension and thus the grains will become more elongated and less spherical because of sorting (Russell, 1955).

The relationships are highly significant as determined

by t-test (Taro, 1967, pp. 391-401) yielding r-values of 0.94 and 0.999 and r^2 values of 0.89 and 0.99 (Table 11) for the phi and millimeter data, respectively.

B. - Thin section values

Relationships between a- and b-axes of quartz grains observed in thin sections of the eighteen sandstones is shown in Figure 8 (c and d) for the phi and millimeter data. The scatter diagrams show close positive linear relationships for both sets of data. The corresponding equations for the phi and millimeter data are:

$$y = \bar{0}.094 + 1.246x \qquad \text{(phi units)} \qquad (14)$$

and

$$y = \bar{0}.0004 + 0.668x \qquad \text{(mm units)} \qquad (15)$$

where y = mean, b-axes, and

x = mean, a-axes.

The regression coefficients (b) are significant from unity at 0.005 level for both phi and millimeter data, whereas the intercept (a) is significantly different from zero (at 0.0005 level) for the phi data and insignificant for the millimeter data. For phi values, thin section measurements show a homoscedastic relationship with sphericity increasing with increase in grain size (lower phi values), and decreasing with finer size (higher phi values).

The relationships are highly significant, yielding correlation coefficient (r) values of 0.98 and 0.999 and r^2 values of 0.96 and 0.99 for the phi and millimeter data, respectively (Table 11).

The data is significantly highly correlated for phi and millimeter values in thin sections and loose grain mounts,

thus measurement of one set of axes is sufficient for an estimation of grain size; the second set contributes little additional information. Also, the long a-axes measurements in both thin section and loose grain mounts yield significantly higher grain "size" values than the corresponding b-axes measurements.

Comparison of Mean Sphericities of Quartz Grains

The average mean sphericity values of quartz grains together with other statistical parameters are listed in Table 12 for different suites of rocks in thin sections and loose grain mounts. Griffith's (1967) averages for mean sphericities of quartz grains according to rock types, and mean sphericity values in thin section and loose grain mount from other sources are listed in the first and second columns of this table. There is a close matching between values of mean sphericity of quartz grains in lithic, subquartzose, and quartzose sandstones and their equivalents from various sources. The average mean sphericity value of 0.7372 for the lithic sandstones matches closely with the mean quartz sphericity values of 0.754 and 0.753 obtained for the Oswego Greywacke by Curray (1949) and Curray and Griffiths (1955) using Krumbein's sphericity technique $(bc/a^2)^{1/3}$. The mean sphericity values of quartz grains in arkose are higher than those listed in column two of Table 12. The mean grain sizes of quartz in thin section and loose grain mount for the arkose sample are 1.4892 and 1.3365 millimeter, respectively, there-

by explaining the higher sphericity values which are directly related to size (regression equation 13). In general, an increase in mean sphericity values of quartz grains is noted from lithic sandstones to quartzose sandstones. Also, the mean sphericity values of quartz grains observed in grain mount are higher than those obtained from thin section. The grain mount sphericity variances are less in comparison to thin section.

A scatter diagram showing relationships between mean sphericity ratios of quartz grains in thin sections and grain mounts for the eighteen sandstones are given in Figure 8e. The diagram shows positive linear relationships between two sets of data, the corresponding regression equation being:

$$y = 0.027 + 0.876x \qquad (16)$$

where y = mean b/a, thin section, and

x = mean b/a, loose grain mount.

The correlation coefficient (r) is highly significant ($r = 0.589$). Therefore, it can be said that over 34 percent (r^2) variability is common between thin section and grain mount mean sphericity, and that nearly 66 percent variation remains "unexplained" by the regression of the two sets of data.

The diagram shows wide scattering of lithic, subquartzose, and quartzose sandstones both below and above the line. However, there is a demarcation of fields of quartzose and subquartzose sandstones together, and the lithic sandstones together on the basis of mean sphericity values. Six out of 9 quartzose and subquartzose sandstones have higher mean

sphericity values than the lithic sandstones.

Comparison of Size-sorting (Standard Deviation)

Agents of transportation tend to sort particles according to the size, shape, and specific gravity of the particles. Also, sorting is influenced by other factors affecting the environment and the conditions of the medium at a particular site. Thus, the degree of sorting measured by the "spread" or dispersion of the size-frequency distribution, is geologically significant.

Standard deviation has been selected as the measure of sorting of the size-distributions discussed herein, measuring the dispersion about the mean or median value.

The sieve analyses standard deviation values used for this study were obtained by transforming Inman's (1952) phi deviation measure using Friedman's (1962, p.746) quadratic regression line. The standard deviation data was treated to similar statistical tests as were applied to means and medians. However, correlation between the three sets of data was significantly lower for the standard deviation than for mean and median. This is probably due to the greater sensitivity of sorting measures to minor differences in size-distributions. Correlations are higher between thin section and grain mount standard deviation values than those obtained for sieve and grain mount, and for sieve and thin section values. Scatter plots showing the relationships between the three sets of data are given in Figure 9 (a,b,c,d) and Figure 10 (a,b,c).

The regression and correlation data are listed in Table 13, and the values of standard deviation obtained from various techniques in Table 14.

The correlation coefficients of standard deviation are 0.435 and 0.987, respectively for phi and millimeter data from thin section and grain mount techniques (Figure 9a & 9b). In comparison to a-axes, the b-axes standard deviations scatter plot in Figure 9c gives highly significant r-values of 0.6988 for the phi data in thin sections and loose grain mounts. The phi deviation values (transformed) from sieve analyses give significantly high r- values of 0.652 and 0.53 when compared with the standard deviation values obtained from loose grain mounts and thin sections, respectively (Table 13, Fig. 9d & 10b). Comparing the standard deviation measured in millimeters, the sieve-grain mount and sieve-thin section comparisons show low negative correlation values of $\bar{0}.36$ and $\bar{0}.319$ respectively (r is significant at the 0.1 level., Figures 10a and c).

The sieve analyses give low phi deviation values for sub-quartzose and quartzose sandstones and high values for lithic sandstones and arkose. The phi deviation values on conversion to a millimeter scale reverse the magnitude of values for quartzose sandstones, lithic sandstones and arkose, thus changing the regression from linear positive trends for phi data to linear negative trends for the millimeter data in grain mount-sieve and sieve-thin section correlations. Accordingly, the differences between values of standard deviation and deviation measure vary with increase or decrease of

values in thin section-grain mount and sieve-thin section comparisons for millimeter and phi data. Also, there is a gradual fall in correlation from grain mount-thin section to grain mount-sieve to sieve-thin section, and from grain mount-sieve to sieve-thin section comparisons for the millimeter and phi data, respectively.

Comparing the standard deviation values in the thin section, grain mount, and sieving techniques, the observed sieve phi deviation values are the highest (14 out of 17 values) because of the inclusion of fine silt sizes and clayey cement (Table 14). Thin section phi standard deviation values of a-axes measurements are on the average higher than grain mount, but with many exceptions (11 out of 18 values).

The scatter diagrams in Figures 9 and 10 show wide scattering of points from the regression line. In general, the subquartzose and quartzose sandstones show less deviation from the regression line as compared to greater deviations shown by lithic sandstones and arkose. However, the plots in Figures 9 (b,d) and 10 (a,b,c) show a compositional grouping of lithic sandstones and arkose separated from subquartzose and quartzose sandstones, with few exceptions. The scatter plot of phi deviation (transformed) and standard deviation shows the best compositional grouping for the millimeter data in sieve and grain mount comparison (Figure 10a). Eight out of 9 quartzose and subquartzose sandstones lie above the regression line (Sample 7 is the exception). All the lithic sandstones and the arkose lie below the regression line. Thus, the sieving technique gives higher millimeter deviation

values for subquartzose and quartzose sandstones and lower values for the lithic sandstones and arkose, against low to moderately high values of standard deviation by the grain mount technique.

Comparison of Measure of Symmetry (Skewness)

Skewness is a measure of symmetry; it measures the departure from a symmetrical distribution by the addition of either a coarser or finer "tail" to the distribution curves. For grain mount and thin section size data, skewness can be calculated from the third moment of the frequency distribution; for sieve data, skewness is calculated graphically utilizing Inman's (1952) "first" and "second" skewness measures given in Appendix A. The "first" skewness measure is sensitive to skew properties occurring in the bulk of the distribution, whereas the "second" skewness measure is most sensitive to the distribution within the tails of the sediments.

The mean phi and millimeter skewness values obtained from the three size-measurement techniques are shown in Table 16, and are plotted on the scatter diagrams in Figure 11 (a,b,c,d,e,f). Corresponding summary statistics for both phi and millimeter skewness are given in Table 15.

Correlations for mean skewness values between the three techniques are lower than the correlations obtained for the parameters of mean and standard deviation. The lower correlations are probably due to the very sensitive nature of the skewness measure, particularly the minor differences at the

tail of the distributions.

Figures 11a and 11b show the plots of mean skewness in thin section and loose grain mount in phi and millimeter units. Highly significant r-values of 0.6389 and 0.708 are obtained from thin section and grain mount techniques for the phi and millimeter data, respectively. Therefore, 40.8 and 50.2 percent of the variation in thin section can be associated with variation in grain mount skewness for the phi and millimeter data, respectively. The grain mount-sieve and sieve-thin section techniques give moderate to low significant correlation values of 0.46 and 0.421 for the "first" skewness measure for phi data (Table 15). In comparison to the "first" skewness, the values derived from the "second" skewness measure show improvement in correlation when plotted against moment skewness values obtained from grain mount ($r = 0.55$) and from thin section ($r = 0.43$) for the phi data (Figures 11c and 11e). For the millimeter data, the correlations between grain mount-sieve ($r = \bar{0}.167$) and sieve-thin section ($r = \bar{0}.306$) techniques are not significant and have negative trends.

In general, a gradual fall in correlation is noted from grain mount-thin section to grain mount-sieve to sieve-thin section correlations for the phi data. This fall in correlation can be explained by increased interaction of complex variables involved in sieve and thin section techniques (poly-component systems) and the role of fine silt sizes and clayey cement.

Skewness values obtained from the three techniques show

consistently higher phi skewness values for sieving analyses in comparison to thin section which on the average show higher values than those obtained from the grain mount technique (Table 16). This can be explained by the inclusion of silt size fractions and clayey cement in sieving analyses, and probably by the underestimation of quartz grain sizes by thin section analysis. Accordingly, size distributions with high positive skewness remain equally unsymmetrical by all three techniques whereas the sieving and thin section techniques give positive unsymmetrical distributions as opposed to symmetrical and negative unsymmetrical distributions in the grain mount.

All the diagrams show wide scatterings of points both below and above the regression line. However, diagrams in figures 11a and 11d indicate a grouping based on rock types. In Figure 11a (grain mount-thin section) 7 out of 9 subquartzose and quartzose sandstones lie below the regression line (7 & 10 being the exceptions), and 6 out of 9 lithic sandstones and arkose lie above the regression line, samples 2, 6, and 12 being the exceptions. A similar separation is noted in Figure 11d, although the correlation between grain mount and sieve skewness is not significant for the millimeter data.

Thus, for the lithic sandstones and arkose the thin section analyses give higher estimates of phi skewness and sieve analyses give lower estimates of millimeter skewness when compared with the values obtained from grain mount analyses.

Comparison of Measure of Peakedness (Kurtosis)

Kurtosis is that property of a frequency distribution that measures the "peakedness" of the curve, and for a normal frequency distribution has a value of 3. For "closed" distributions, such as those generated by thin section and grain mount size measurements, kurtosis can be calculated from the fourth moment; for "open" distributions, such as those generated by sieving analyses, kurtosis or peakedness conventionally is estimated graphically from the cumulative frequency distribution using the phi and millimeter kurtosis equations given in Appendix A.

The mean phi kurtosis values obtained from the size-distributions of 18 sandstone samples are given in Table 18 and the scatter diagrams of the same are plotted in Figures 12 (a,b,c). The corresponding regression equations are listed in Table 17.

The regressions of the three sets of data show inconsistent linear trends of zero to highly significant correlation values in the grain mount, thin section, and sieving techniques for the phi and millimeter data. No correlation exists between grain mount and thin section phi kurtosis values. However, the grain mount and sieve techniques give highly significant correlation (r = 0.55., Fig. 12b) for the phi data. The correlation between sieve and thin section technique drops to a not significant negative value of $\bar{0}.134$. This is in contradiction to linear positive significant correlations obtained by Friedman (1958) and Rosenfeld _et al_ (1953) for the

phi data. The millimeter kurtosis data show moderate to highly significant correlations between thin section-grain mount ($r = 0.442$., Fig. 12a);between grain mount-sieve ($r = 0.649$., Fig. 12c); and not significant very low correlation between the sieve and thin section techniques ($r = 0.114$). The significant correlation between the grain mount and sieve techniques shows that the differences in kurtosis increases with the increase in kurtosis values for both phi and millimeter data and vice-versa. However, the inconsistency in regression trends and nil to moderately high correlations for mean phi and millimeter kurtosis indicates that peakedness is more a function of differences in techniques than of differences between samples. Also, the relationships between the three sets of data can be attributed to the extreme sensitivity of the kurtosis measure to variations and fluctuations in the extremes of the size-distributions.

The mean kurtosis values obtained from the three techniques are listed in Table 18. The sieve size-distributions of the 18 sandstones show lower phi kurtosis values than those obtained from either thin section or grain mount technique. The value of "graphic" kurtosis for a normal frequency size-distirbution is 1, thus explaining the lower magnitude of sieve phi kurtosis values. The thin section analyses, on the average, give higher mean phi kurtosis values than those derived from the grain mount analyses.

The scatter diagrams in Figure 12 (a,b,c) show wide scattering of points. In Figure 12c, a slight indication of compositional grouping by rock types is noted between grain

mount and sieve analyses for the millimeter kurtosis. Seven out of the 9 subquartzose and quartzose sandstones lie above the line and 2 below the regression line, whereas 5 out of the 8 lithic sandstones and arkose lie below the line (Samples 6, 13, and 18 being the exceptions). Thus, the sieve analyses on the average have lower millimeter kurtosis estimation for lithic sanstones and arkose than for subquartzose and quartzose sandstone.

Comparison of Total Distributions

Four samples were randomly selected, one each from the lithic, subquartzose and quartzose sandstones, and the arkose, for comparison of total size-distributions obtained from grain mount, thin section, and sieve analyses. Cumulative curves based on number and weight frequency data from grain mount, thin section, and sieve techniques are plotted on arithmetic-ordinate probability paper in Figure 13. The statistical parameters of the four sandstones as obtained from grain mount, thin section, and sieve techniques are listed in Table 19. The clay and matrix contents of the sandstones obtained from point counting in thin sections are given in column 6 of this table. A comparison of size-distributions indicate that the phi medians in sieve analyses are shifted towards higher phi sizes because of the fine fractions and clayey cement. This shift is more prominent in lithic sandstone(clay cement plus matrix = 20 percent). Sorting, skewness, and kurtosis values are likewise affected

in the sieve analyses. Sieve frequency histograms in Figure 3 are more skewed towards fine sizes in comparison to those obtained from number frequency data of a-axes in thin section and grain mount analyses. The cumulative curves derived from sieve analyses also show marked skewness towards fine sizes because of the content of either matrix or clayey cement for lithic sandstone (Fig. 13a), subquartzose sandstone (Fig. 13b), and arkose (Fig. 13d).

Comparison of cumulative curves in Figure 13 show that the grain mount cumulative curves, in general, occupy the extreme position towards lower phi sizes, whereas the sieve cumulative curves occupy the other extreme position towards higher phi sizes, with the thin section cumulative curves occupying a position more or less in between the two. The thin section and grain mount curves show deviations from sieve cumulative curves beyond 70 percent for the lithic sandstone; at 80 percent for subquartzose sandstone; 40 percent for arkose, and negligible (less than 1 percent) deviation in the case of quartzose sandstone. The grain mount and thin section cumulative curves are relatively close, with some deviation for the arkose sample. The grain mount and thin section cumulative curves run closely parallel to each other for subquartzose and quartzose sandstones and exhibit a "cross over" for the lithic sandstone and arkose. The sieve cumulative curves also cross and recross the thin section cumulative curves. The crossing of thin section cumulative curves by sieve cumulative curves may be a random error and may not be characteristic of techniques. However, Friedman (1958, p.403)

found that for many fine grained rocks the...

> "curves exhibit a 'cross over' in which the sieve size-distribution curve crosses and recrosses the thin section cumulative curve"...

whereas Rosenfeld _et al_ (1953) had earlier stated that the cumulative curves determined by thin section and sieve analyses generally run parallel to one another.

The comparison of total distributions show that:

1. The grain mount size-distributions more nearly approximate the log normal distribution in comparison to thin section and sieve size-distributions;
2. Thin section size-distributions run close to grain mount size-distributions except in the finer size range for the arkose where some divergence in distribution is noted;
3. The sieve-distributions run in close conformity to grain mount size-distributions in the 0.10 to 99.4 percent range for quartzose sandstone; in the 15 to 80 percent range for the subquartzose sandstone; in the .05 to 70 percent range for lithic sandstone; and in the 2 to 20 percent range for arkose; and show significant divergence in the higher ranges, excepting quartzose sandstone; and
4. That the differences in size-distributions are more a function of differences in techniques than differences in the samples.

INTERRELATIONSHIPS OF SIZE PARAMETERS

It has been demonstrated that the size frequency distributions of grain mount data are more homogenous and tend more to be log normal than those derived from thin section amd sieve analyses. It is for these reasons that the grain mount data have been chosen to investigate the interrelations of the four size parameters.

Mean Size versus Standard Deviation

Figure 14 (a and b) shows plots of mean loose grain size values against standard deviations in phi units and millimeters. A negative linear trend showing an increase in standard deviation with decrease in phi size (coarser grain sizes) is noted, the correlation coefficient (r) being $\bar{0}.627$, significant at the 0.05 percent level. An extremely correlated positive linear trend is shown for millimeter data, the value of r being 0.9937. Scatter plot 14b clearly demonstrates that sandstone samples with mean grain size between 0.10 and 0.225 millimeter are better sorted (lower values of std. dev.) than those having the mean grain size larger than 0.25 millimeter. This is in conformity with the results obtained by Hough (1942) on Cape Cod Bay sediments; Shukri and Higazi (1944) on Red Sea sediments; and Krumbein and Aberdeen (1937), on Bartaria Bay sediments. The latter showed that the sorting is a function of the mean grain size, and that samples having a median diameter near 0.18 millimeter are the best

sorted, the sorting increasing in magnitude for median diameters greater or less than 0.18 millimeter. Inman (1949) observed a similar relationship between median diameter and sorting for all water environments. Griffiths (1951), on the basis of his studies in the Caribbean area, confirmed the conclusions reached earlier by Inman and others. Folk (1957) showed that a broad M-shaped trend or part of a trend may develop with the minimas (of best sorting) coinciding with prominent modes in sediments, and maximas (of poorest sorting) corresponding to mixed modes in sediments. The scatter plots in Figure 14a and 14b only demonstrate the relationships between mean grain size and standard deviation for fine grained sediments and a few samples of medium sand, and that the results closely match those of the earlier workers for sediments in the fine and medium-coarse sand size range.

Mean Size versus Skewness

Figure 14c shows a plot of mean grain size values against mean skewness values in phi units. Regression of the two sets of values produces a negative not significant trend (significant at the 0.15 level) which shows symmetrical distributions for samples having mean grain size around 3.7 phi (0.074 mm). This is in contradiction to results obtained by Hough (1942); Shukri and Higazi (1944) and Krumbein and Aberdeen (1937), who showed best sorting and symmetrical distributions for sediments having mean grain size around 0.18

millimeter. Inman (1949) compared trends between mean diameter and skewness obtained by these authors, all of which show curvi-linear and sinuous relationships. As such, a simple linear regression of the two sets of data for fine and medium sand size material only, is not likely to exhibit the complete relationships which may exist between mean diameter and skewness.

Mean Size versus Kurtosis

A scatter plot of mean grain size versus kurtosis in phi units is shown in Figure 14d. The value of the correlation coefficient is not significant (r = 0.2509) and therefore the interrelation between mean grain size and kurtosis is not discussed.

Standard Deviation versus Skewness

Although the scatter plot in Figure 14e appears to show a positive linear trend for values of standard deviation and skewness in phi units, the correlation between the two sets of values is not significant, the coefficient of correlation being 0.2598 (significant at less than the 0.15 level). However, the scatter plot between sieve phi deviation and sieve skewness (first skewness measure) in Figure 14f shows a highly significant positive linear trend (r = 0.7) showing an increase in values of phi deviations with increase in values of skewness. Samples 9 and 17 have nearly symmetrical distributions with mean grain diameters of 0.15 millimeter.

Philip et al (1968) found an interrelation between standard deviation and skewness indicating that fine skewed sediments are better sorted.

Standard Deviation versus Kurtosis

Figure 14g shows a negative linear trend between mean size and kurtosis with a low significant correlation (r = 0.3983). The scatter plot shows that the kurtosis increases with sorting; the better the sorting the higher is the kurtosis of the distribution. Sample 7 has a mean grain diameter of 0.18 millimeter and is well sorted and has a normal kurtosis. Samples with mean diameter coarser than 0.18 millimeter show higher standard deviation and a platykurtic distribution because of the mixing of the two modes in considerable proportions. Samples with mean diameter in the fine to very fine sand (less than 0.18 mm) range have a very small subordinate mode in very fine sand to silt grade with the greater percentage of grains still clustered around the modal class, giving rise to a peaked distribution. Philip et al (1968) found similar relationship between leptokurtosis and best sorting.

Skewness versus Kurtosis

Figure 14h shows the scatter plot of kurtosis versus skewness. Plotting of points showed two separate linear trends and thus the regression lines for the two trends were separately computed. The two trends cross at 0 skewness and

3.08 kurtosis indicating normal symmetrical distribution for samples plotted at this point. The first regression line indicates a positive linear trend with high significant correlation ($r = 0.9437.$, Table 20). It is crossed by the second regression line having a negative linear trend with significant high correlation ($r = \bar{0}.8496.$, Table 20). The first trend indicates that samples with mean diameter around 0.18 millimeter have a nearly symmetrical distribution and normal kurtosis, and are best sorted. Samples with a mean diameter greater than 0.18 millimeter and a second coarser mode in medium sand added to fine sand mode in considerable proportions, results in a platykurtic distribution. Such samples may also comparatively show a greater value of standard deviation than those samples having normal symmetrical distribution. Samples with mean diameter of less than 0.18 millimeter will develop a prominent central mode with continued sorting. Slight addition of a silt mode at this stage may result in a peaked unsymmetrical (positively skewed) distribution. Philip *et al* (1968) showed that fine skewed sediments are leptokurtic to very leptokurtic. The first trend reasonably demonstrates this relationship. The second trend shows that with continued sorting the samples will approach the mean diameter of 0.18 millimeter, and a normal symmetrical curve with best sorting will result at 0 skewness and 3 kurtosis. Continued sorting associated with the removal of fines and addition of a coarser mode will result in a peaked unsymmetrical distribution (negatively skewed) and the peakedness will

increase with sorting. This reconfirms the conclusion reached earlier from Figure 14g. This trend also shows how initial sediments of lithic sandstone composition may ultimately, through several cycles of reworking, lead to subquartzose and quartzose rocks.

SUMMARY OF RESULTS

Eighteen sandstone samples varying widely in composition and texture were subjected to grain size analysis by grain mount, thin section, and sieving techniques. Comparison of results shows that:

1. Frequency histograms of means and medians in phi units show that the grain mount size-distributions are more homogenous and more nearly log normal than those obtained from thin section and sieving techniques. Frequency histograms of means and medians plotted as independent variables in millimeters are unsymmetrical and coarsely skewed in comparison to near symmetrical or finely skewed histograms obtained from phi data;

2. (a) Mean and median grain sizes obtained by the three techniques are closely correlated. The grain mount technique (a-axes) yields the highest value the thin section (random axes) an intermediate value and the sieving technique the lowest value of mean grain size;

   (b) regression of the two sets of data show that 69 to 98 percent of the variability is common for phi and millimeter data in the grain mount-thin section, grain mount-sieve, and sieve-thin section comparisons, the only exception being the mean phi values compared in the grain mount and thin section techniques;

(c) the observed differences between means, or median and mean grain size values, obtained from the three techniques change with changing grain size, thus a constant correction factor cannot be employed in translating the results of one technique to another technique. The regression equations with statistically determined confidence limits can be utilized in transforming the values of sieve median to mean grain mount and thin section, or vice-versa;

(d) compositional grouping by rock types has been noted in sieve and thin section plots for phi data, and in plots of differences in medians and means, by the three techniques, against mean grain mount.

3. (a) The sphericity frequency histograms are unimodal and quasi-symmetrical for thin section and loose grain mount;

(b) the a- and b-axes are extremely correlated in thin section and grain mount for both phi and millimeter data. Regression of two sets of data shows that 88 to 99 percent of the variation in b-axes can be associated with variation in a-axes in thin section and grain mount for millimeter and phi data, and that a-axis gives the maximum measure of size;

(c) shape is directly related to mean grain size in grain mount for millimeter data and in thin sec-

tion for phi data. Thus, the grains become more spherical with increase in size, and elongated with decrease in grain size;

(d) the thin section underestimates the mean sphericity in comparison to the loose grain mount. The mean sphericity values of quartz grains calculated from either of the two techniques closely match values obtained by other authors, and show an increase from lithic to quartzose sandstones.

4. (a) Lower correlations are obtained for standard deviations in comparison to means. Correlation for standard deviations vary from extremely significant positive linear trends (0.68-0.53 for phi and 0.98 to $\bar{0}.319$ for millimeter) to negative not significant trends. The observed sieve phi deviation values are the highest, the thin section on the average intermediate, and the loose grain mount the lowest;

(b) a gradual fall in correlation is noted from grain mount-thin section to grain mount-sieve to sieve-thin section comparisions for millimeter data, and from grain mount-sieve to sieve-thin section comparisons for the phi data, an effect of increased interaction of variables;

(c) the sieving technique yields the highest values of millimeter deviation for quartzose and subquartzose sandstones and lowest values for lithic

sandstones and arkose, as opposed to lowest or moderate estimates derived from the grain mount technique for these two groups of sandstones.

5. (a) The correlation for skewness values vary from 0.64 to 0.43 for phi data and from 0.7 to $\bar{0}.167$ for the millimeter data from the three techniques;

   (b) a gradual fall in correlation is noted from grain mount-thin section to grain mount-sieve to sieve-thin section comparisons for the phi data;

   (c) the sieving technique yields highest estimate, thin section an intermediate estimate, and loose grain mount on the average, the lowest estimate of mean phi skewness.

6. (a) Correlations for mean kurtosis vary from zero to 0.649 for the phi and millimeter data in the three techniques. The grain mount and sieving techniques show significant correlation in comparison to inconsistent not significant regression lines between thin section and sieving techniques for the phi and millimeter data, respectively. The correlation once again shows a fall from grain mount-sieve to sieve-thin section;

   (b) the sieving technique yields the highest values, thin section, on the average, an intermediate value, and loose grain mount technique the lowest estimate of mean phi kurtosis.

7. Comparison of the total distributions shows that the grain mount size-distributions tend to be more symme-

trical than those derived from thin section and sieving analyses. The thin section size-distributions run close to grain mount size-distributions excepting for some divergence in the finer size range for arkose. The sieve size-distributions show increasing divergence from the grain mount size-distributions in the finer size ranges in going from subquartzose to lithic sandstones to arkose; negligible or no divergence in the case of quartzose sandstone.

8. Mean grain size is a function of sorting. A highly significant negative trend for phi data (r = $\bar{0}.627$) and an extremely significant positive linear trend for millimeter data (r = 0.99) indicates that sorting becomes poorer with increase in mean grain size from very fine sand to the medium coarse sand size range.
9. Skewness is probably a function of sorting and mean phi skewness may increase with increase in mean phi standard deviation.
10. The value of mean phi kurtosis increases with decrease in mean phi standard deviation.
11. A double interrelation exists between mean phi skewness and mean phi kurtosis. Skewness increases or decreases with increase in mean phi kurtosis values.

GENERAL CONCLUSIONS

Comparison of loose grain mount, thin section and sieving analyses show that no constant relationships could be recognized in size parameters between the three techniques. On the contrary, the relationships differ between groups of samples of similar composition, and between techniques; lack of a consistent relationship indicates that elimination of different sediment variables and their interactions by the three techniques influences the size measures.

All three techniques yield different but related measures of size. Thin section and loose grain mount, being direct techniques, yield better estimates of size than those obtained by sieving analysis. The present study shows that the size-distributions obtained from the loose grain mount analyses approximate more closely the log normal distribution than those derived from either thin section or sieving analyses; grain mount size-distributions also better demonstrate the interrelation among size parameters.

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APPENDIX A

Graphical and Moment Measures

Moment and graphical statistical measures of Folk (1968), Kelley (1923), Trask (1932), and Inman (1952) have been used to compute size parameters from number and weight frequency data.

<u>Median</u>

This is a measure of central tendency; the median diameter is read on the x-scale directly from the cumulative curve at 50 percent frequency.

<u>Mean</u>

Mean is the first moment and is given by the formula:

$$M=m_1$$

<u>Phi Deviation Measure</u>

Phi deviation of a frequency distribution is half the distance between the 84 and 16 percentiles and is given by the formula:

$$\text{Phi Deviation}=\frac{(\emptyset 84-\emptyset 16)}{2}$$

For a normal distribution, the phi deviation is 0.5. The value of phi deviation increases with poorer sorting. Standard deviation in millimeters is obtained by converting the phi deviation values. Inman's phi deviation values were converted to moment standard deviation through Friedman's (1962) regression lines.

In moment statistics, standard deviation is the second moment and is given by the formula:

$$\text{standard deviation} = \sqrt{m_2}$$

where m_2 is the second moment about the mean.

Standard error of the means

This is a moment measure based on the principle of greater precision with increasing measurements, and is defined as:

$$\text{standard error of the means } (\sigma\bar{x}) = \sigma/\sqrt{n}$$

Skewness (Inman, 1952, Trask, 1932)

Two graphical measures of skewness using 5, 16, 50, 84 and 95 percentiles from the cumulative curves have been calculated using Inman's formula. Trask's skewness coefficient was used to calculate the skewness measure in millimeters.

$$\text{First Phi Skewness Measure} = \frac{\phi 16 + \phi 84 - 2(Md\phi)}{\phi 84 - \phi 16}$$

This measure is independent of the spread of the curve and is related to moment skewness a_3 by a ratio of 6:1. It is sensitive to skew properties occurring in the bulk of the distribution. The phi skewness is zero for a symmetrical distribution. The second phi measure is most sensitive to the distribution within the tail of the sediments. The formula for second phi skewness is as follows:

$$\text{Second Phi Skewness} = \frac{1/2\ (\phi 5 + \phi 95) - Md\phi}{\phi 84 - \phi 16}$$

$$= \frac{\phi 5 + \phi 95 - 2Md\phi}{\phi 84 - \phi 16}$$

Trask's skewness coefficient is given by the formula:

$$sk = \frac{Q_1 Q_3}{Md^2}$$

Skewness is the third moment and is defined as:

$$a_3\phi = m_3/\sigma^3$$

where m_3 is the third moment about the mean.

Measure of Peakedness

Folk (1968, p.48) defined kurtosis as the ratio between sorting in the "tails" of the distribution curve and the sorting in the central portion of the curve. In a normal curve the phi diameter interval between Ø5 and Ø95 points should be exactly 2.44 times the phi diameter interval between Ø25 and Ø75 points. In the case of a normal curve the value of kurtosis is 1. Kurtosis increases with better sorting in the central portion of the curve and decreases with poorer sorting in the central portion in comparison to sorting in the tails. Folk's graphic kurtosis is given by the following formula:

$$K_G = \frac{(\text{Ø}95-\text{Ø}5)}{2.44(\text{Ø}75-\text{Ø}25)}$$

The verbal limits of graphic kurtosis are: K_G under 0.67, very platykurtic; 0.67-0.90, platykurtic; 0.9-1.11, mesokurtic; 1.11-1.50, leptokurtic; K_G over 1.5-3.0, very leptokurtic; over 3.0, extremely leptokurtic.

Kelly (1923) defined kurtosis (millimeter) as:

$$K_{qa} = \frac{(P_{90}-P_{10})}{Q_3-Q_1}$$

where Q_3 is equivalent to the 25 percentile, Q_1 to the 75 percentile, P_{90} to the 10 percentile, and P_{10} to the 90 percentile.

In moment statistics, kurtosis is the fourth moment and is defined as:

$$B_2\text{Ø} = m_4/\sigma^4$$

where m_4 is the fourth moment about the mean. The value of $B_2Ø$ for a normal distribution is 3. It increases with more peakedness and decreases with more platykurtic distribution.

APPENDIX B

Withdrawal Times for Pipette Analysis

For quartz or clay minerals at 24°C, these times work out as follows (Folk, 1968, p.40).

Depth 'cm'	Phi	Mm	Times of withdrawal	Sample No.
	Start suspension		0 sec.	
20	4.0	0.0625	20 sec	1
20	4.5	0.044	1 min. 45 sec	2
			RESTIR	
	Start suspension		0 sec	
10	5.0	0.031	1 min. 45 sec.	3
10	5.5	0.0221	3 min. 28 sec.	4
10	6.0	0.0156	6 min. 58 sec.	5
10	7.0	0.0078	28 min.	6
10	8.0	0.0039	1 hr. 51 min.	7
10	9.0	0.0020	7 hr. 24 min.	8

For withdrawal made at odd times, the diameter of the particle was computed by the following formula:

$$T_{min.} = \frac{\text{Depth in Cm}}{1500A.d^2(\text{mm})}$$

"where 'T' is the time in minutes, d^2 is the square of the particle diameter in millimeter, and 'A' is a constant which depends upon the viscosity of the water (a function of temperature), the force of gravitation, and density of the particle." Value of A at 24°C is 3.93.

Computation of percent coarser

Folk's (1968, p.38-40) formula has been used to compute the percent coarser from pipette sedimentation analysis. Let us presume that the fine sediments are uniformly distributed throughout the entire 1000ml column and the first withdrawal is made after 20 seconds of suspension. Accordingly, then the amount of mud in each withdrawal is 1/50 of the total amount of mud still remaining suspended at that particular depth and time. The first withdrawal after 20 seconds incorporates the particles of all sizes, therefore if the weight of the first withdrawal is multiplied by 50 (after subtracting dispersant weight), the weight of the entire amount of mud in the cylinder is obtained. Similarly the number of grams percent at any size can be computed and the cumulative percentage is obtained by the following formula:

$$\text{Cumulative Percent Coarser} = \frac{100(S+F-P)}{S+F}$$

where S is the weight of sand caught on 4 phi screen, F represents the total amount of mud from the first withdrawal (20 sec.), P is the quantity obtained from subsequent pipette withdrawals and therefore, the percentage of sand in the sample is given by 100S/(S+F). An example of the computation is given in the following table.

Sample No. 16

Phi	Mm	Time at 24°C	Weight spl. and beaker	Weight beaker	Weight Sample	Less dispersent 0.125 gms	Times 50	Cumulative percent
Csr. 4.................obtained by wet sieving.......86.38(S)								
4	.0625	20s	30.28	29.81	0.47	0.345	13.8(F)	
4.5	.044	1m45s	36.76	36.36	0.4	0.275	11.0(P)	89.18
5	.031	1m45s	36.59	36.24	0.35	0.225	9.0(P)	91.01
5.5	.0221	3m28s	40.61	40.3	0.31	0.185	7.4(P)	92.61
6	.0150	7m30s	41.055	40.79	0.265	0.14	5.6(P)	94.11
7	.0078	28m	98.975	98.75	0.225	0.1	4.0(P)	96.005
8	.0039	1hr51m	68.07	67.87	0.20	0.075	3.0(P)	97.005
9	.002	3hr42m	68.825	68.64	0.185	0.06	2.4(P)	97.6

APPENDIX C

Computer Programs on Grain Size Parameters

The APL-360 programs of 'MVSD', 'FREQ', 'PLOT', 'KURT-SKEW', and 'GRAPH' are included here to stimulate the performance of further comparative studies of grain-size parameters of moderately- and poorly-sorted sands. The functions and output of each program are given below:

<u>MVSD Program</u>

Functions:

```
      ∇MVSD[⎕]∇
    ∇ T←MVSD X;N;M;VAR;SD
[1]   SD←(VAR←(+/[1](X-(ρX)ρM←(+/[1]X)÷N)*2)÷(N←(ρX)[1])-1
      )*0.5
[2]   T←⍉(3,ρM,ι0)ρM,VAR,SD
    ∇
```

Output of Sample Number 2 in phi units by thin section analysis is:

```
      4 RND MVSD 2⍟E1[1;]×0.014

 ¯1.9303              0.2477              0.4977
```

<u>FREQ Program</u>

Functions:

```
      ∇FREQ[⎕]∇
    ∇ T←P FREQ X;K;M;SD;F;W;N;A;V;C
[1]   T←((N←P[3]),4+2×K←4=ρP)ρ0
[2]   T[ιN;4]←+/(ιN)∘.=⌈(X-F←P[1])÷W←P[2]
[3]   T[ιN;1]←V←F+W×(ιN)-1
[4]   T[ιN;2]←V+W
[5]   T[ιN;3]←V+W÷2
[6]   →(K=0)/0
[7]   T←(0,(Nρ1),0)\[1]T
[8]   C← 0.196854 0.115194 0.000344
      0.019527
[9]   SD←((+/(X-M←(+/X)÷ρX)*2)÷(ρX)-1)*
      0.5
[10]  A←((V,V[ρV]+W)-M)÷SD
[11]  V←ι0
[12]  V←V,((F<0),F≥0)/(1-W),W←1-0.5×(1++/C×(|F←A[1+ρV])*ι
      4)*¯4
[13]  →((ρV)<N+1)/12
[14]  V←V,1
[15]  T[;5]←(ρX)×V+.×((ιN)∘.=ιN)-(ιN)∘.=(ιN←N+2)-1
[16]  T[;6]←T[;4]-T[;5]
[17]  T[; 5 6]←0.1×⌊0.5+T[; 5 6]×10
    ∇
```

Output of number frquency data for Sample Number 2 at 0.25 phi interval by thin section analysis is:

```
10 2 DFT ¯0.75 ¯0.25 15 0 FREQ 2⍉E1[1;]×0.014

 0.00       0.00       0.00       0.00      198.20    ¯198.2
 0
¯0.75      ¯1.00      ¯0.87       2.00       ¯4.30       6.3
 0
¯1.00      ¯1.25      ¯1.12      12.00      ¯11.10      23.1
 0
¯1.25      ¯1.50      ¯1.37      23.00      ¯21.60      44.6
 0
¯1.50      ¯1.75      ¯1.62      39.00      ¯32.90      71.9
 0
¯1.75      ¯2.00      ¯1.87      52.00      ¯39.40      91.4
 0
¯2.00      ¯2.25      ¯2.12      22.00      ¯36.90      58.9
 0
¯2.25      ¯2.50      ¯2.37      24.00      ¯26.80      50.8
 0
¯2.50      ¯2.75      ¯2.62      14.00      ¯15.40      29.4
 0
¯2.75      ¯3.00      ¯2.87       5.00       ¯6.80      11.8
 0
¯3.00      ¯3.25      ¯3.12       4.00       ¯2.30       6.3
 0
¯3.25      ¯3.50      ¯3.37       2.00       ¯0.60       2.6
 0
¯3.50      ¯3.75      ¯3.62       1.00       ¯0.20       1.2
 0
¯3.75      ¯4.00      ¯3.87       0.00        0.00       0.0
 0
¯4.00      ¯4.25      ¯4.12       0.00        0.00       0.0
 0
¯4.25      ¯4.50      ¯4.37       0.00        0.00       0.0
 0
 0.00       0.00       0.00       0.00      200.00    ¯200.0
 0
```

PLOT Program

Functions:

```
      ∇PLOT[⎕]∇
    ∇ A PLOT B;C;D;F;G;H;I;J;L;T;Y;HZ;NB;VT;PT;ST;ISV;U
[1]   PC←'○*∘∨∧⎕'
[2]   HS←1
[3]   ST← 1 2 5
[4]   SM← 5 10
[5]   →((0=×/(2ρA),ρB), 3 2 1 <ρρB)/0,PRKERR,PLOTL2,PLOTL3
[6]   →PLOTL3×ρρρB←⍉(2,D)ρ(⍳D←ρ,B),B
[7]   PLOTL2:B←B[1;;]
[8]   PLOTL3:Y←1+⍳(ρB)[2]-1
[9]   C←((⌈/⌈/B[;Y])-⌊/⌊/B[;Y]),(⌈/B[;1])-⌊/B[;1]
[10]  F←|(2ρA)÷C+(C=0)×B[1; 2 1]+B[1; 2 1]=0
[11]  F←(ST[+/(⌊0.0001+F×10*-G)∘.≥ST])×10*G←⌊10⍟F
[12]  G←(SM÷F)×⌊(((⌊/⌊/B[;Y]),⌊/B[;1])×F÷SM←16⌊SM⌈ 1 4
[13]  B[;1]←⌊0.5+F[2]×B[;1]-G[2]
[14]  B[;Y]←⌊0.5+F[1]×B[;Y]-G[1]
[15]  H←SM×⌈(((⌈/⌈/B[;Y]),⌈/B[;1])÷SM
[16]  NB←G[1]+(SM[1]÷F[1])×0,⍳H[1]÷SM[1]
[17]  HZ←G[2]+(SM[2]÷F[2])×0,⍳H[2]÷SM[2]
[18]  0ρST←6ρ~ISV←1≠U←9
[19]  PLOTL4:VT←∨/0>NB←NB×10*U-ST[6-ISV]←I←1+⌈/⌊10⍟|(NB≠0)/NB
[20]  PT←⌊1+10|PT-1|PT←1E¯5+(|NB)∘.÷10*¯1+⌽⍳U
[21]  L←U+1-(⌽((C←ρNB)ρ1)∧.=PT)⍳0
[22]  →((U>T←VT+⌈/I,(L+L≠I),(I≤0)×2+L-I),ST[2-ISV]←ST[2-ISV]∨L≥U-VT+L
      >I)/ 3 2 +⌶26
[23]  →(¯1+⌶26)×ρρρST[4-ISV]←I←1
[24]  →PLOTL4×ρρNB←SM[1+~ISV]×¯1+⍳C
[25]  PT←(-VT+0⌈1-I)⌽PT
[26]  PT←(,PT)×J←,⍉(⌽ρPT)ρ(,⍉(1≠PT)∨.∧(⍳U)∘.≤⍳VT⌈I-1),(C×U+1-I←VT+I⌈I
      ≤0)ρ1
[27]  →(2+⌶26)×⍳~VT
[28]  PT[(U-+/(C,U)ρJ)+U×¯1+⍳C]←11×NB<0
[29]  PT←(~(⍳U+J)∊(I+J),⍳¯1+J←U-T)\(1 0 +C,U)ρPT,Uρ0
[30]  PT[⍳C;I+J]←12
[31]  PT←' 0123456789¯.'[1+PT[;⍳U-1]]
[32]  →PLOTL13×⍳~ISV
[33]  L←1,H[2]ρ0×C←H[1]
[34]  PLOTL8:L←(L×HS×C≠0)⌈1,H[2]ρ0
[35]  L[1+(D≠0)/B[;1]]←(D≠0)/D←(C=B[;Y])⌈.×Y
[36]  →(C≠0)/PLOTL11
[37]  L←L⌈0=(SM[2]÷2)|0,⍳H[2]
[38]  PLOTL11:PT[((ρPT)[1],1+C÷SM[1])[1+0=SM[1]|C];],(' |',(ρY)ρPC)[1
      +L]
[39]  →(0≤C←C-1)ρPLOTL8
[40]  →(U=U←SM[2]-~ISV←~ρρNB←,HZ)ρPLOTL4
[41]  PLOTL13:(SM[2]-9)⌽(,(0 0 ,(U-1)ρ1)\PT),' '
[42]  →(ST[1 3 2 4],1)/ 1 3 5 7 10 +⌶26
[43]  ('ORIGIN AND SCALE FACTOR FOR ORDINATE: ';G[1],÷F[1])
[44]  →(2+⌶26)×⍳0=ST[3]
[45]  ('SCALE FACTOR FOR ORDINATE: ';10*ST[5]-1)
[46]  →(2+⌶26)×⍳0=ST[2]
[47]  ('ORIGIN AND SCALE FACTOR FOR ABSCISSA: ';G[2],÷F[2])
[48]  →0×⍳0=ST[4]
[49]  ('SCALE FACTOR FOR ABSCISSA: ';10*ST[6]-1)
[50]  →0
[51]  PRKERR:'THE RIGHT ARGUMENT OF  PLOT  MUST HAVE RANK ≤ 3.'
    ∇
```

The frequency histogram for the size distribution of Sample Number 2 is:

```
25 15 PLOT 2 12 23 39 52 22 24 14 5 4 2 1

50|     o
  |     o
  |    oo
  |    oo
  |    oo
25|   ooo o
  |   ooooo
  |   oooooo
  |  ooooooo
  |  ooooooooo
 0|o    |    |oo  |    |
  0         10        20
```

KURTSKEW Program
Functions:

```
      ∇KURT∆SKEW[⎕]∇
    ∇ KURT∆SKEW X;Y;T;I
[1]   T←(3,ρX)ρX,Y,-2⍟Y←0.014×X
[2]   ' INITIAL VALUE          MM          PHI'
[3]   ' '
[4]   4 RND⍉T
[5]   I←2
[6]   A←T[1;]
[7]   MOMENT←(+/[1](A-((+/A)÷ρA))∘.* 2 3 4)÷ρA
[8]   ('SKEWNESS= ';4 RND MOMENT[2]÷MOMENT[1]*3÷2)
[9]   ('KURTOSIS= ';4 RND MOMENT[3]÷MOMENT[1]*2)
[10]  ' '
[11]  →(3=I←I+1)/6
[12]  'FIRST PAIR ARE MM MOMENTS,SECOND ARE PHI MOMENTS.'
    ∇
```

The conversions of hypothetical values XX into millimeters and phi units and skewness and kurtosis values are as given on the following page.

```
      XX
5.5  3.4  4.8  5.9  6.9  4.3  2.9  5.9  3.9
     4.8  3.7  2.9  4.7  5


      KURT∆SKEW XX
 INITIAL VALUE          MM        PHI


   5.5                 0.077            3.699
   3.4                 0.0476           4.3929
   4.8                 0.0672           3.8954
   5.9                 0.0826           3.5977
   6.9                 0.0966           3.3718
   4.3                 0.0602           4.0541
   2.9                 0.0406           4.6224
   5.9                 0.0826           3.5977
   3.9                 0.0546           4.195
   4.8                 0.0672           3.8954
   3.7                 0.0518           4.2709
   2.9                 0.0406           4.6224
   4.7                 0.0658           3.9258
   5                   0.07             3.8365
SKEWNESS= 0.1874
KURTOSIS= 2.2407

SKEWNESS= 0.1874
KURTOSIS= 2.2407

FIRST PAIR ARE MM MOMENTS,SECOND ARE PHI MOMENTS.
```

GRAPH Program

Functions:

```
      ∇GRAPH[⎕]∇
    ∇ GRAPH;A;B;N;P;Q;R;X;Y;Z;B0;B1;MX;MY;SE;SX;SY;TV;VX;VY;RSQ;SDX;
      SDY;VUX;VUY
[1]   'TYPE IN X VALUES OR NAME OF VECTOR OF X VALUES FOR WHICH Y VAL
      UES ARE KNOWN--'
[2]   X←⎕
[3]   'TYPE IN Y VALUES OR NAME OF VECTOR OF Y VALUES FOR WHICH X VAL
      UES ARE KNOWN--'
[4]   Y←⎕
[5]   →((ρX)=(ρY))/8
[6]   'NUMBER OF X VALUES MUST BE THE SAME AS NUMBER OF Y VALUES. TRY
       AGAIN.'
[7]   →1
[8]   SX←((A←+/(X-MX←(+/X)÷N)*2)÷(N←(ρX))-1)*0.5
[9]   SY←((B←+/(Y-MY←(+/Y)÷N)*2)÷N-1)*0.5
[10]  B0←MY-MX×B1←(+/(X-MX)×(Y-MY))÷A
[11]  SE←((B×1-RSQ←(R←B1×SX÷SY)*2)÷N-2)*0.5
[12]  'USE THE NEXT THREE STATEMENTS TO DRAW YOUR BEST FIT LINE:'
[13]  'MEAN OF X VALUES IS ';3 RND MX
[14]  'VALUE FOR Y AT THIS POINT ON THE GRAPH IS ';3 RND(B0+(B1×MX))
[15]  →(B0<0)/18
[16]  'WHEN X IS ZERO, Y IS ';3 RND B0
[17]  →19
[18]  'WHEN Y IS ZERO, X IS ';3 RND((0-B0)÷B1)
[19]  'IN Y=A+(B×X), A IS ';3 RND B0;'; B IS ';3 RND B1
[20]  VX←(+/(Y-(B0+(B1×X)))*2)÷(ρX)-1
[21]  'VARIATION OF X FROM GRAPH LINE IS ';2 RND VX
[22]  SDX←VX*0.5
[23]  'STANDARD DEVIATION OF X FROM GRAPH LINE IS ';3 RND SDX
[24]  VY←(+/(X-((Y-B0)÷B1))*2)÷(ρY)-1
[25]  'VARIATION OF Y FROM GRAPH LINE IS ';2 RND VY
[26]  SDY←VY*0.5
[27]  'STANDARD DAVIATION OF Y FROM GRAPH LINE IS ';3 RND SDY
[28]  TV←B1÷SB1←(SY÷SX)÷((N-2)÷(1-RSQ))*0.5
[29]  'A IS';4 RND B0
[30]  'B IS ';4 RND B1
[31]  'STANDARD ERROR OF B IS :';4 RND SB1
[32]  'T-VALUE IS :';4 RND TV
[33]  'STANDARD ERROR OF ESTIMATE OF Y IS :';4 RND SE
[34]  'SIMPLE CORRELATION COEFFICIENT R IS :';4 RND R
[35]  'R SQUARED IS :';4 RND RSQ
    ∇
```

The regression and correlation of mean grain size and standard deviation values in millimeters is:

```
      GRAPH
TYPE IN X VALUES OR NAME OF VECTOR OF X VALUES FOR WHICH Y
      VALUES ARE KNOWN--
⎕:
      MLM
TYPE IN Y VALUES OR NAME OF VECTOR OF Y VALUES FOR WHICH X
      VALUES ARE KNOWN--
⎕:
      SDLM
USE THE NEXT THREE STATEMENTS TO DRAW YOUR BEST FIT LINE:
MEAN OF X VALUES IS 0.264
VALUE FOR Y AT THIS POINT ON THE GRAPH IS 0.102
WHEN Y IS ZERO, X IS 0.048
IN Y=A+(B×X), A IS ¯0.023; B IS 0.472
VARIATION OF X FROM GRAPH LINE IS 0
STANDARD DEVIATION OF X FROM GRAPH LINE IS 0.015
VARIATION OF Y FROM GRAPH LINE IS 0
STANDARD DAVIATION OF Y FROM GRAPH LINE IS 0.031
A IS¯0.0228
B IS 0.4723
STANDARD ERROR OF B IS :0.0133
T-VALUE IS :35.4277
STANDARD ERROR OF ESTIMATE OF Y IS :0.015
SIMPLE CORRELATION COEFFICIENT R IS :0.9937
R SQUARED IS :0.9874
```

APPENDIX D

Raw Data for Size Distributions

of Eighteen Sandstone Samples

Table 3 Raw Data for Sieve Analyses

Percent in 0.25 Phi Interval

Sample No.	-1.0	-1.0 to -0.75	-0.75 to -0.50	-0.50 to -0.25	-0.25 to 0.0	0 to 0.25	0.25 to 0.50	0.50 to 0.75	0.75 to 1.0	1.0 to 1.25	1.25 to 1.50
1	-	-	-	-	-	-	-	-	-	-	0.07
2	-	-	-	-	-	-	-	0.05	0.14	1.06	3.73
3	-	-	-	-	-	-	-	-	-	-	2.46
4	-	-	-	-	-	-	-	-	-	0.20	0.20
5	-	-	-	-	-	-	-	-	-	0.50	3.11
6	-	-	-	-	-	-	-	1.82	3.26	13.83	13.73
7	-	-	-	-	-	-	-	-	-	0.40	0.36
8	-	-	-	-	-	-	-	-	-	-	0.67
9	-	-	-	-	-	-	-	-	-	-	0.11
10	-	-	-	-	-	-	-	-	-	0.004	0.001
11	-	-	-	-	-	-	-	-	-	-	0.14
12	-	-	-	-	-	-	-	-	-	0.04	0.20
13	-	-	-	-	-	-	-	-	-	1.14	0.94
14	-	-	-	-	-	-	-	-	-	-	2.03
15	-	-	-	-	-	-	-	-	-	-	0.03
16	-	-	-	-	-	-	-	-	-	-	1.40
17	-	-	-	-	-	-	-	-	-	-	0.41
18	2.87	2.94	3.94	-	9.13	-	-	20.27	3.02	5.53	4.35

Table3(continued)

Percent in 0.25 Phi Interval

Sample No.	1.50 to 1.75	1.75 to 2.0	2.0 to 2.25	2.25 to 2.50	2.50 to 2.75	2.75 to 3.0	3.0 to 3.25	3.25 to 3.50	3.50 to 3.75	3.75 to 4.0	>4.0
1	0.47	2.08	8.16	13.38	20.73	21.15	13.33	7.39	4.09	2.53	0.61
2	11.0	14.58	14.65	9.61	8.08	4.94	4.26	1.55	2.35	1.55	1.21
3	6.18	8.46	10.44	10.19	13.44	3.46	12.19	0.73	6.76	3.30	1.06
4	0.36	0.46	1.0	3.46	11.66	14.72	14.48	3.50	5.10	4.30	1.86
5	10.54	14.54	15.15	9.42	8.48	5.47	4.20	3.45	2.96	2.10	2.08
6	19.24	11.91	8.20	3.50	3.49	1.77	1.32	0.97	0.89	0.39	0.79
7	0.94	1.64	2.40	1.77	4.58	11.68	9.24	12.77	9.39	8.04	5.07
8	0.74	0.83	1.21	1.46	2.78	4.15	7.22	26.76	20.03	9.67	6.94
9	0.51	0.86	1.71	2.54	6.53	20.75	30.53	19.98	5.74	2.43	0.67
10	-	0.02	-	0.14	0.97	9.46	61.78	4.0	16.20	1.44	0.98
11	0.38	2.17	6.30	7.36	10.81	36.06	26.79	4.36	2.81	0.86	0.21
12	1.40	2.65	6.45	8.32	13.32	6.72	16.94	4.02	2.75	3.40	1.0
13	1.58	3.10	4.09	2.11	3.11	1.95	21.85	2.67	18.16	5.75	1.24
14	7.19	11.90	15.17	11.51	10.83	6.43	4.44	3.68	2.98	1.55	3.42
15	1.13	2.23	6.75	18.98	32.22	11.45	4.94	2.53	1.70	1.64	0.80
16	4.82	8.77	14.45	13.08	16.05	11.84	6.75	3.54	2.33	1.56	1.45
17	0.63	1.63	3.05	3.67	7.10	6.57	28.47	2.26	28.42	6.83	1.37
18	4.17	3.09	3.24	2.56	3.04	2.64	1.96	1.61	1.47	1.04	0.88

Table 4 Raw Data for Thin Section Analyses: Long a-axes in quartz grains

Percent in 0.25 Phi Interval

Sample No.	-2.25 to -2.0	-2.0 to -1.75	-1.75 to -1.50	-1.50 to -1.25	-1.25 to -1.0	-1.0 to -0.75	-0.75 to -0.50	-0.50 to -0.25
1	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
18	4.0	-	-	9.50	7.50	11.0	12.0	21.5

Table 4 (continued)

Percent in 0.25 Phi Interval

Sample No.	-0.25 to 0.0	0 to 0.25	0.25 to 0.50	0.50 to 0.75	0.75 to 1.0	1.0 to 1.25	1.25 to 1.50	1.50 to 1.75
1	-	-	-	-	-	-	1.0	2.0
2	-	-	-	-	1.0	6.0	11.50	19.50
3	-	-	-	-	-	3.50	7.0	8.50
4	-	-	-	-	-	-	-	0.50
5	-	-	-	0.50	1.50	4.50	16.50	20.50
6	-	-	0.50	0.50	3.0	11.0	19.50	19.0
7	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	0.50	1.0
10	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	1.0
12	-	-	-	-	-	-	-	4.0
13	-	-	-	-	-	-	-	0.50
14	-	-	-	2.0	7.0	18.0	20.0	20.50
15	-	-	-	-	-	-	-	1.50
16	-	-	-	1.0	-	0.50	2.0	7.0
17	-	-	-	-	-	1.50	-	1.0
18	7.0	8.0	3.0	2.0	1.0	4.0	4.0	1.50

Table 4 (continued)

Percent in 0.25 Phi Interval

Sample No.	1.75 to 2.0	2.0 to 2.25	2.25 to 2.50	2.50 to 2.75	2.75 to 3.0	3.0 to 3.25	3.25 to 3.50	3.50 to 3.75
1	5.50	7.0	13.50	14.50	19.0	13.50	13.0	5.0
2	26.0	11.0	12.0	7.0	2.5	2.0	1.0	0.50
3	10.50	16.50	18.50	14.0	8.5	3.0	5.0	0.50
4	4.50	4.50	19.50	19.0	26.0	5.0	11.50	8.0
5	23.0	24.50	8.50	4.0	3.50	1.0	0.50	-
6	17.50	9.50	9.50	4.50	3.0	0.50	1.0	1.0
7	0.50	0.50	5.50	10.50	17.0	12.50	16.0	13.50
8	-	-	-	0.50	7.50	17.50	27.0	26.0
9	1.0	3.0	11.50	17.50	25.50	14.0	13.50	5.50
10	0.50	2.0	9.0	20.50	33.0	15.5	10.0	5.50
11	2.0	5.50	11.50	15.0	27.50	14.0	12.50	6.50
12	7.0	7.50	6.0	11.50	11.50	7.0	5.0	3.50
13	1.0	-	2.50	9.0	27.0	18.0	27.50	6.50
14	10.50	8.0	3.50	2.0	3.5	1.0	2.0	0.50
15	14.0	15.0	25.50	21.50	11.0	5.50	1.0	4.50
16	13.0	11.50	11.50	18.0	16.50	7.50	6.50	3.50
17	2.0	4.50	11.50	17.0	24.0	8.50	19.0	8.0
18	1.0	1.0	0.50	1.0	-	0.50	-	-

Table 4 (continued)

Sample No.	Percent in 0.25 Phi Interval 3.75 to 4.0	4.0 to 4.25	4.25 to 4.50	4.50 to 4.75	4.75 to 5.0	5.0 to 5.25	5.25 to 5.50	5.50 to 5.75	5.75 to 6.0
1	2.0	2.0	1.50	0.50	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-
3	2.0	1.0	0.50	1.0	-	-	-	-	-
4	2.0	3.50	0.50	-	0.50	-	-	-	-
5	0.50	-	-	1.0	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-
7	9.50	4.50	3.50	4.0	2.0	0.50	-	-	-
8	13.50	3.50	2.50	0.50	1.50	-	-	-	-
9	4.50	2.0	0.50	-	-	-	-	-	-
10	2.50	-	1.0	0.50	-	-	-	-	-
11	2.50	0.50	1.0	0.50	-	-	-	-	-
12	4.50	3.0	8.0	3.0	8.50	4.0	2.50	2.0	0.50
13	4.0	3.0	-	0.50	-	-	-	-	-
14	0.50	-	1.0	-	-	-	-	-	-
15	-	-	0.50	-	-	-	-	-	-
16	1.50	-	-	-	-	-	-	-	-
17	2.0	0.50	-	0.50	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-

The percentages for the grouped data were obtained by dividing the number frequencies of 200 observations by 2.

Table 5 Raw Data for Grain Mount Analyses: Long a-axes in Quartz Grains

Percent in 0.25 Phi Interval

Sample No.	-1.50 to -1.25	-1.25 to -1.0	-1.0 to -0.75	-0.75 to -0.50	-0.50 to -0.25	-0.25 to 0.0	0.0 to 0.25	0.25 to 0.50	0.50 to 0.75
1	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	1.0	3.0
3	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	0.50
6	-	-	-	-	-	-	-	2.0	0.50
7	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-
18	4.50	14.50	6.0	9.50	15.50	16.50	12.0	10.50	2.50

Table 5 (continued)

Percent in 0.25 Phi Interval

Sample No.	0.75 to 1.0	1.0 to 1.25	1.25 to 1.50	1.50 to 1.75	1.75 to 2.0	2.0 to 2.25	2.25 to 2.50	2.50 to 2.75	2.75 to 3.0
1	-	-	1.50	6.0	7.50	12.50	16.50	12.0	16.50
2	5.0	7.50	18.50	16.0	9.50	8.0	13.50	5.50	5.50
3	-	0.50	3.50	11.0	21.50	16.0	21.50	14.0	8.0
4	-	0.50	2.0	4.0	16.50	26.0	25.0	16.50	7.0
5	0.50	8.50	10.0	20.0	18.0	13.50	9.50	9.0	5.50
6	9.0	13.0	15.0	20.0	13.50	8.0	5.50	5.50	3.50
7	-	-	-	0.50	-	3.0	12.0	15.50	24.0
8	-	-	-	-	0.50	-	-	6.50	27.50
9	-	-	1.0	0.50	3.0	4.0	16.50	31.0	29.50
10	-	-	-	-	1.50	4.0	23.0	33.0	28.0
11	-	1.0	2.0	6.0	13.0	14.50	26.0	20.0	11.0
12	-	1.50	3.0	5.50	13.50	13.50	14.0	8.50	4.0
13	-	1.0	0.50	3.50	4.0	4.50	15.0	20.0	15.50
14	-	-	2.0	9.0	18.50	10.50	9.50	9.50	12.50
15	-	-	3.0	5.0	25.0	22.50	19.0	10.50	5.50
16	-	1.50	4.50	9.50	13.50	14.50	18.0	18.50	12.50
17	-	-	-	1.0	2.0	4.50	18.50	16.50	32.0
18	1.50	3.50	2.50	1.0	-	-	-	-	-

Table 5 (continued)

Sample No.	Percent in 0.25 Phi Interval							
	3.0 to 3.25	3.25 to 3.50	3.50 to 3.75	3.75 to 4.0	4.0 to 4.25	4.25 to 4.50	4.50 to 4.75	4.75 to 5.0
1	13.0	6.0	5.0	2.0	–	0.5	–	–
2	2.0	4.50	–	–	–	–	–	–
3	2.50	1.50	–	–	–	–	–	–
4	2.0	–	0.5	–	–	–	–	–
5	2.50	2.50	–	–	–	–	–	–
6	3.0	1.0	–	–	–	–	–	–
7	22.50	13.50	4.50	4.50	–	–	–	–
8	19.0	29.50	10.50	3.0	1.0	1.50	1.0	–
9	7.0	5.50	1.50	0.50	–	–	–	–
10	5.50	3.0	1.50	0.50	–	–	–	–
11	4.0	2.50	–	–	–	–	–	–
12	3.50	6.50	9.50	12.50	2.0	1.0	1.0	0.50
13	12.0	17.50	2.50	2.0	0.50	1.50	–	–
14	9.0	10.50	4.0	3.0	1.50	0.50	–	–
15	3.0	3.0	1.50	1.50	–	–	0.50	–
16	4.50	0.50	2.0	0.50	–	–	–	–
17	11.0	13.0	1.50	–	–	–	–	–
18	–	–	–	–	–	–	–	–

The percentages for the grouped data were obtained by dividing the number frequencies of 200 observations by 2.

Table 1 List of Sample Numbers, Localities, and Stratigraphic and Lithologic Data of Eighteen Sandstone Samples

Res. Coun. Alta. Sample No.	Sample No. used in this thesis	Locality	Rock Unit	Age	Rock Types	General Depositional Environment
BM62-12	1	Northwest Alta.	Unnamed	Pleist.	Quartzose SS	Fluviatile
BM67-10	2	Foothills, Central Alta.	Saunders Gp.?	Tertiary?	Lithic SS	Fluviatile
BM67-3	3	do	Brazeau Gp.	U. Cret.	Lithic SS	Fluviatile
BM67-15	4	East-central Alta.	"Pale beds"	U. Cret.	Lithic SS	Fluviatile
BM59-289	5	Foothills, S. Alta.	Belly River Fm.	U. Cret.	Lithic SS	"Shoreline"
JJ20-199	6	Northwest Alta.	Wapiti Gp.	U. Cret.	Lithic SS	Fluviatile
BM59-233	7	Northeast B.C.	Dunvegan Fm. (subsurface)	U. Cret.	Lithic SS	Fluviatile
NP-2A	8	West-central Alta.	Cardium Fm.	U. Cret.	Quartzose SS	Marine
BM59-198	9	Northwest Alta.	Pouce Coupe SS	U. Cret.	Quartzose SS	Marine
BM59-65	10	Northwest Alta.	Cadotte Ss	L. Cret.	Quartzose SS	"Shoreline"
65-HS-65	11	Northeast Alta.	Pelican Ss	L. Cret.	Quartzose SS	Marine
BM59-113	12	Northwest Alta.	Notikewin Ss	L. Cret.	Lithic SS	Marine

Table 1(continued)

Res. Coun. Alta. Sample No.	Sample No. used in this thesis	Locality	Rock Unit	Age	Rock Types	General Depositional Environment
RG65-191	13	Northeast Alta.	Clearwater Fm.	L. Cret.	Lithic SS	Marine
M2-71-190	14	Foothills, S. Alta.	Blairmore Gp.	L. Cret.	Lithic SS	Fluviatile
CPR-10-22-4	15	Southeast Alta.	"Basal Quartz"	L. Cret.	Quartzose SS	Nonmarine?
BM59-467	16	Northeast B.C.	Halfway Fm.	Triassic	Quartzose SS	Marine
XY-02	17	Colorado	Fountain Fm.	Penn.	Quartzose SS	"Shoreline"?
XY-07	18	Colorado	Fountain Fm.	Penn.	Arkose	Fluviatile

Table 2 Mineral Composition Obtained by Point Counting of Eighteen Thin Sections

Samples No.	Grains					Matrix	Cements				Uncertain and Accessory Minerals
	Quartz and Quartzite	Chert	Felds.	Micas	R.F.		Quartz	Carbs.	Clays	Ferrug.	
1	47	11	13	-	3	-	-	-	-	25.5	0.5
2	15	5.5	13	1	42.5	4.5	-	3	15.5	-	-
3	25.5	3	18.5	-	30.0	-	-	2.5	20.0	0.5	-
4	13.5	4.5	12.5	1.5	15.5	8	-	0.5	42.5	1.0	0.5
5	42.5	7.5	23	2	11.0	2	-	7	5.0	-	-
6	18.5	15	7.5	-	45.5	-	-	-	12	0.5	1
7	47	8.5	8	-	21.5	-	-	-	12.5	2.5	-
8	61	5.5	2	0.5	16.5	10	-	-	1.5	1.0	2
9	72	4	3	-	7	1.5	5	-	7	0.5	-
10	32	20	4.5	-	3	-	0.5	-	-	40.0	-
11	84	9.5	2	-	0.5	-	-	-	3	1.0	-
12	18.5	6.5	23	0.5	25	13.5	-	-	5.5	6	1.5
13	34.5	6	4.5	-	31	17	-	5.5	1	0.5	-
14	22.5	16.5	8.5	-	32.5	-	-	17.5	-	-	2.5
15	61	7	0.5	-	10	5	3.5	-	8.5	4.5	-
16	66	6.5	1.5	-	-	-	19.5	4.5	0.5	1.5	-
17	63	-	8	-	0.5	0.5	0.5	16	11.5	-	-
18	42	2	47	-	0.5	-	-	8.5	-	-	-

Table 6 Summary Statistics in Phi Units for Size Distributions of Eighteen Sandstone Samples Obtained from Sieving, Thin Section, and Grain Mount Analyses (Long a-axes in Quartz Grains in Thin Section and Grain Mount)

Sample No.		Md/Mean	Std. Dev.	Variance	Std. Error	Skewness	Kurtosis
1	S	2.815	0.5475	-	-	0.0867	0.844
	TS	2.839	0.6035	0.3642	0.0427	0.1921	3.0534
	GM	2.5996	0.6106	0.3729	0.0432	0.0379	2.7383
2	S	2.34	1.84	-	-	0.67	1.191
	TS	1.9303	0.4977	0.2477	0.0352	0.6692	3.5573
	GM	1.8633	0.709	0.5027	0.0501	0.4452	2.7707
3	S	2.76	1.415	-	-	0.4275	1.155
	TS	2.338	0.673	0.453	0.0476	0.6724	3.9536
	GM	2.214	0.4471	0.1999	0.0316	0.1969	2.5764
4	S	3.49	4.365	-	-	0.832	-
	TS	2.882	0.5624	0.3163	0.0398	0.5655	3.3063
	GM	2.258	0.3856	0.1487	0.0273	0.093	3.5967
5	S	2.38	1.27	-	-	0.5197	0.887
	TS	1.875	0.5557	0.3088	0.0393	1.51	8.094
	GM	1.964	0.5651	0.3193	0.04	0.3905	2.5532
6	S	1.728	1.315	-	-	0.6137	1.775
	TS	1.7717	0.5457	0.2978	0.0386	0.7912	3.8407
	GM	1.7118	0.6514	0.4244	0.0461	0.8241	4.3609

Table 6(continued)

Sample No.		Md/Mean	Std. Dev.	Variance	Std. Error	Skewness	Kurtosis
7	S	3.625	1.335	–	–	0.4045	1.385
	TS	3.35	0.6324	0.3999	0.0447	0.5013	2.7761
	GM	2.939	0.4062	0.165	0.0287	0.0682	3.015
8	S	3.55	0.5625	–	–	0.2977	1.675
	TS	3.5019	0.394	0.1553	0.0279	0.9228	3.5019
	GM	3.2129	0.3769	0.1421	0.0267	0.7885	4.8357
9	S	3.14	0.745	–	–	0.0201	0.761
	TS	2.9395	0.4972	0.2472	0.0352	$\underline{0}.1192$	3.632
	GM	2.6886	0.3789	0.1436	0.0268	$\bar{0}.2993$	4.4296
10	S	3.155	0.29	–	–	0.4655	1.051
	TS	2.9367	0.4115	0.1693	0.0291	0.8665	4.8051
	GM	2.6827	0.3095	0.0958	0.0219	0.4747	4.1901
11	S	2.87	0.34	–	–	$\bar{0}.1617$	1.182
	TS	2.8988	0.4968	0.2468	0.0351	$\underline{0}.3008$	3.4667
	GM	2.3463	0.4461	0.199	0.0315	$\bar{0}.017$	2.9354
12	S	3.15	2.11	–	–	0.637	0.842
	TS	3.3397	1.1508	1.3243	0.0814	0.3035	1.9667
	GM	1.881	0.5926	0.3512	0.0419	0.3386	1.9771
13	S	3.6	2.655	–	–	0.6949	0.702
	TS	3.1488	0.4449	0.198	0.0315	0.515	5.6007
	GM	2.7858	0.5737	0.3292	0.0406	$\bar{0}.1014$	3.4374

Table 6(continued)

Sample No.		Md/Mean	Std. Dev.	Variance	Std. Error	Skewness	Kurtosis
14	S	2.535	1.27	-	-	0.4842	1.324
	TS	1.6634	0.6685	0.4469	0.0473	1.5261	5.9084
	GM	2.5585	0.6933	0.4806	0.049	0.3404	2.1729
15	S	2.67	0.875	-	-	0.5657	1.902
	TS	2.464	0.451	0.2029	0.0319	0.9809	4.479
	GM	2.281	0.5267	0.2775	0.0372	1.261	5.3487
16	S	2.63	0.9175	-	-	0.286	1.523
	TS	2.4995	0.6068	0.3682	0.0429	$\bar{0}.048$	2.8934
	GM	2.306	0.53	0.281	0.0374	0.0662	2.8464
17	S	3.24	0.58	-	-	$\bar{0}.017$	1.055
	TS	2.8861	0.5348	0.2861	0.0378	$\bar{0}.3121$	3.843
	GM	2.768	0.3939	0.1552	0.0279	$\bar{0}.3187$	2.7635
18	S	1.375	2.22	-	-	0.3167	0.864
	TS	0.3041	0.9743	0.9493	0.0689	0.9503	3.9926
	GM	0.2568	0.7123	0.5074	0.0504	0.4529	2.869

GM= Grain Mount, TS = Thin Section and S = Sieving Technique

Table 7 Summary Statistics in Millimeters for Size Distributions of Eighteen Sandstone Samples Obtained from Sieving, Thin Section, and Grain Mount Analyses (Long a-axes in Quartz Grains in Thin Section and Grain Mount)

Sample No.		Md/Mean	Std. Dev.	Variance	Std. Error	Skewness	Kurtosis
1	S	0.1435	0.71	-	-	0.9638	0.2344
	TS	0.1521	0.0636	0.004	0.0045	0.9859	4.1026
	GM	0.1804	0.0794	0.0063	0.0056	1.2277	5.121
2	S	0.2075	0.29	-	-	0.5541	0.28
	TS	0.2772	0.088	0.0078	0.0062	0.2814	2.8141
	GM	0.3072	0.1397	0.0195	0.0099	0.644	3.1522
3	S	0.1475	0.383	-	-	0.675	0.2856
	TS	0.2183	0.0937	0.0088	0.0066	0.7366	3.4272
	GM	0.2258	0.0686	0.0047	0.0049	0.5038	2.8642
4	S	0.0894	0.0485	-	-	0.0454	-
	TS	0.1455	0.0528	0.0028	0.0037	0.5348	3.4314
	GM	0.2166	0.0588	0.0035	0.0042	0.8987	4.5967
5	S	0.193	0.42	-	-	0.6171	0.2914
	TS	0.2903	0.0954	0.0091	0.0067	0.4151	4.2553
	GM	0.2754	0.1014	0.0103	0.0072	0.4196	2.7314
6	S	0.317	0.409	-	-	0.7827	0.2349
	TS	0.3125	0.1066	0.0114	0.0075	0.3538	3.4361
	GM	0.3343	0.1354	0.0183	0.0096	0.5908	3.5546

Table 7(continued)

Sample No.		Md/Mean	Std. Dev.	Variance	Std. Error	Skewness	Kurtosis
7	S	0.087	0.44	–	–	0.6986	0.2528
	TS	0.1071	0.0431	0.0019	0.003	0.4653	2.9549
	GM	0.1352	0.0384	0.0015	0.0027	0.7903	4.0339
8	S	0.0856	0.692	–	–	0.8048	0.2209
	TS	0.0913	0.0227	0.0005	0.0016	$\bar{0}.0565$	2.8175
	GM	0.1114	0.0274	0.0008	0.0019	0.5104	5.7376
9	S	0.1145	0.608	–	–	1.2068	1.9736
	TS	0.1382	0.0492	0.0024	0.0035	1.3707	6.7697
	GM	0.1607	0.0459	0.0021	0.0032	1.7282	8.6094
10	S	0.124	0.83	–	–	0.8955	0.2316
	TS	0.1356	0.0357	0.0013	0.0025	0.2838	3.7294
	GM	0.1592	0.0332	0.0011	0.0048	0.4109	3.9013
11	S	0.137	0.81	–	–	1.0581	0.1995
	TS	0.142	0.0482	0.0023	0.0034	0.7919	3.8171
	GM	0.2062	0.0653	0.0043	0.0043	0.9227	4.14
12	S	0.125	0.235	–	–	0.5746	0.2809
	TS	0.1306	0.091	0.0083	0.0064	0.8641	3.301
	GM	0.1787	0.0946	0.0089	0.0067	0.4978	2.5048
13	S	0.0828	0.16	–	–	0.4138	0.2043
	TS	0.118	0.0366	0.0013	0.0026	1.4668	8.8319
	GM	0.1571	0.0672	0.0045	0.0048	1.5225	6.2662

Table 7(continued)

Sample No.		Md/Mean	Std. Dev.	Variance	Std. Error	Skewness	Kurtosis
14	S	0.173	0.42	–	–	0.6209	0.2856
	TS	0.3443	0.1239	0.0153	0.0088	0.0963	3.0075
	GM	0.1889	0.0834	0.0069	0.0059	0.3388	2.1122
15	S	0.157	0.554	–	–	1.7164	0.0189
	TS	0.1894	0.0527	0.0028	0.0037	0.0318	2.6824
	GM	0.218	0.0675	0.0045	0.0048	0.0043	3.1897
16	S	0.1625	0.538	–	–	0.9283	0.2497
	TS	0.1932	0.0859	0.0074	0.0061	1.547	7.6596
	GM	0.216	0.08	0.006	0.006	0.8557	3.5109
17	S	0.1065	0.68	–	–	0.0826	0.2723
	TS	0.1453	0.0611	0.0037	0.0043	2.1244	10.4619
	GM	0.1525	0.044	0.0019	0.0031	1.067	4.4108
18	S	0.39	0.233	–	–	0.3908	0.2742
	TS	1.4892	0.842	0.7089	0.0595	0.9721	4.2526
	GM	1.3365	0.6082	0.3699	0.043	0.4992	2.2058

GM = Grain Mount, TS = Thin Section and S= Sieving Technique

TABLE 8

Summary Statistics for Sphericity Values in Eighteen Sandstone Samples Obtained from Thin Section and Grain Mount Analyses
Sphericity: Ratio of b- and a-axes in Quartz Grains

Sample No.		Mean	Std. Dev.	Variance	Std. Error
1	TS	0.6858	0.1674	0.028	0.0118
	GM	0.7575	0.1347	0.0181	0.0095
2	TS	0.6571	0.1471	0.0216	0.0104
	GM	0.7479	0.1473	0.0217	0.0104
3	TS	0.6657	0.1749	0.0306	0.0124
	GM	0.7524	0.1233	0.0153	0.0087
4	TS	0.6453	0.1651	0.0273	0.0117
	GM	0.7357	0.1361	0.0185	0.0096
5	TS	0.6892	0.1599	0.0256	0.0113
	GM	0.7426	0.1421	0.0202	0.01
6	TS	0.6881	0.1401	0.0196	0.0099
	GM	0.7346	0.1379	0.019	0.0098
7	TS	0.6907	0.1519	0.0231	0.0107
	GM	0.7636	0.1312	0.0172	0.0093
8	TS	0.6969	0.1594	0.0254	0.0113
	GM	0.7504	0.1342	0.018	0.0095
9	TS	0.7116	0.1568	0.0246	0.0111
	GM	0.7622	0.1203	0.0145	0.0085
10	TS	0.7072	0.1571	0.0247	0.0111
	GM	0.7744	0.1249	0.0156	0.0088
11	TS	0.6689	0.1642	0.0264	0.0115
	GM	0.735	0.1616	0.0261	0.0114
12	TS	0.6648	0.1537	0.0236	0.0109
	GM	0.7232	0.1323	0.0175	0.0094
13	TS	0.6719	0.1723	0.0297	0.0122
	GM	0.7334	0.1422	0.0202	0.0101
14	TS	0.6587	0.1517	0.023	0.0107
	GM	0.7277	0.1416	0.0201	0.01

TABLE 8(continued)

Sample No.		Mean	Std. Dev.	Variance	Std. Error
15	TS	0.6761	0.1604	0.0257	0.0113
	GM	0.7461	0.1163	0.0135	0.0082
16	TS	0.7181	0.1447	0.0209	0.0102
	GM	0.751	0.14	0.02	0.0098
17	TS	0.6911	0.1591	0.0253	0.0113
	GM	0.747	0.1422	0.0202	0.0101
18	TS	0.6785	0.164	0.0269	0.0116
	GM	0.7666	0.1475	0.0217	0.0104

S = Sieving Technique
TS = Thin Section
GM = Grain Mount

Table 9 Linear Regression and Correlation Data for Means and Medians in Phi and Millimeter Units for Size Distributions of Eighteen Sandstone Samples Analyzed by Grain Mount, Thin Section and Sieving Techniques.

Equation No.	Technique	Regression Formula ($y = a+bx$)	Se	Sb	r	r^2	Pb	Pa
(6)	TS-GM(Ø)	$y = 0.218+1.008x$	0.45	0.17	0.829****	0.69	M 0.50	0.5-0.25
(7)	TS-GM(mm)	$y = \bar{0}.0456+1.14x$	0.06	0.04	0.988****	0.98	L 0.005	L 0.010
(8)	GM-S(Ø)	$y = 0,999+0.8x$	0.35	0.13	0.834****	0.69	L 0.10	L 0.005
(9)	GM-S(mm)	$y = 0.093+0.245x$	0.05	0.04	0.829****	0.69	L 0.0005	L 0.05
(10)	TS-S(Ø)	$y = \bar{0}.7759+1.166x$	0.32	0.12	0.92****	0.85	L 0.10	L 0.025
(11)	TS-S(mm)	$y = \bar{0}.2578+3.257x$	0.18	0.54	0.832****	0.69	L 0.0005	L 0.010

Symbols are as follows: r = Correlation Coefficient; r^2 = Correlation Coefficient Squared; Se = Standard Error of Estimate of y; Sb = Standard Error of b; Pb = Probability Level of Regression Coefficient b being 1; Pa = Probability Level of Intercept (a) being Zero; L = Less Than; M = Greater Than; * = Significant at 0.05 Level; ** = Significant at 0.01 Level; *** = Significant at 0.005 Level; **** = Significant at 0.0005 Level; GM = Grain Mount; TS = Thin Section, and S = Sieving Technique

Table 10 Mean a-axes and Median Size in Phi Units for Size Distributions of Eighteen Sandstone Samples Analyzed by Grain Mount, Thin Section, and Sieving Techniques

Sample No.	Mean G.M. Observed	Mean Thin Section Observed	Mean Thin Section Corrected	Mean Thin Section Obs.-Corr.	Median Sieve Observed	Median Sieve Corrected	Median Sieve Obs.-Corr.
1	2.5996	2.8393	2.8383	0.001	2.815	3.3971	-0.582
2	1.8633	1.9303	2.0962	-0.1659	2.34	2.6615	-0.3215
3	2.2142	2.338	2.4499	-0.1119	2.76	3.012	-0.252
4	2.2578	2.8822	2.4938	0.378	3.49	3.0556	0.4344
5	1.9642	1.8753	2.1979	-0.3226	2.38	2.7623	-0.6823
6	1.7118	1.7717	1.9434	-0.1717	1.728	2.51	-0.782
7	2.939	3.3506	3.1805	0.1701	3.625	3.7361	-0.111
8	3.2129	3.5019	3.4566	0.0453	3.55	4.0097	-0.4597
9	2.6886	2.9395	2.928	0.011	3.14	3.486	-0.346
10	2.6827	2.9367	2.9221	0.1228	3.155	3.4801	-0.325
11	2.3463	2.8988	2.583	0.3158	2.87	3.144	-0.274
12	1.8811	3.3397	2.1141	1.2256	3.15	2.6793	0.4707
13	2.7858	3.1488	3.026	0.1228	3.6	3.5831	0.02
14	2.5585	1.6634	2.7969	-1.1335	3.53	3.356	0.179
15	2.281	2.4641	2.5172	-0.053	2.67	3.0788	-0.4088
16	2.306	2.4995	2.5424	-0.043	2.63	3.1037	-0.4737
17	2.7681	2.8861	3.008	-0.122	3.24	3.5654	-0.3254
18	0.2568	0.3041	0.4768	-0.1727	1.375	1.0566	0.3184

GM = Loose Grain Mount; TS = Thin Section, and S = Sieving Technique

Table 11 Linear Regression and Correlation Data for Mean a- and b- axes (Phi and Millimeter Units) and b/a Ratios for Quartz Grains in Grain Mount and Thin Section Techniques

Equation No.	Technique	Regression Formula ($y = a+bx$)	Se	Sb	r	r^2	Pb	Pa
(12)	GM(Ø)	$y = 0.0216+1.186x$	0.280	0.106	0.942****	0.88	L 0.05	M 0.25
(13)	GM(mm)	$y = \bar{0}.0099+0.7879x$	0.003	0.004	0.999****	0.99	L 0.0005	L 0.025
(14)	TS(Ø)	$y = \bar{0}.094+1.246x$	0.218	0.067	0.977****	0.96	L 0.005	L 0.0005
(15)	TS(mm)	$y = \bar{0}.0004+0.668x$	0.004	0.003	0.999****	0.99	L 0.0005	M 0.25
(16)	TS-GM	$y = 0.027+0.876x$	0.017	0.307	0.589***	0.35	M 0.25	

GM = Grain Mount; TS = Thin Section Technique

Table 12 Summary Statistics for Mean Quartz Sphericity Values Arranged According to Mineral Composition of Eighteen Sandstone Samples Analyzed by Grain Mount and Thin Section Techniques

Rock Types		Griffiths Average Means	Means from Various Sources	Mean	Standard Deviation	Variance	Standard Error	N
Arkose	(TS)		0.649[a]	0.678	0.164	0.026	0.011	200
	(GM)	0.733[f]	-	0.766	0.147	0.021	0.010	200
Lithic Sandstones	(TS)	-	0.6691[b]	0.667	0.158	0.0251	0.011	1600
	(GM)	0.750[f]	0.686[c]	0.737	0.138	0.019	0.009	1600
Subquartzose Sandstones	(TS)	-	0.6506[d]	0.695	0.159	0.025	0.011	800
	(GM)	-	-	0.761	0.131	0.025	0.009	800
Quartzose Sandstones	(TS)	-	0.677[e]	0.6942	0.156	0.024	0.011	1000
	(GM)	0.772[f]	0.700[c]	0.7483	0.137	0.018	0.009	1000
Total	(TS)	-	-	0.683	0.159	0.025	0.011	3600
	(GM)	-	-	0.753	0.138	0.019	0.009	3600

Source of references as quoted by Griffiths (1967, p. 123-135): a-Griffiths et al., 1956; b-Emery, 1954; c-Bokman, 1957; d-Griffiths and Rosenfeld, 1953; e-Rosenfeld, 1953; f-Griffiths, 1967.

Table 13 Linear Regression and Correlation Data for Standard Deviations in Phi and Millimeter Units for Size Distributions of Eighteen Sandstone Samples Analyzed by Grain Mount, Thin Section and Sieving Techniques

Equation No.	Technique	Regression Formula ($y = a+bx$)	Se	Sb	r	r^2	Pb	Pa
(17)	TS-GM(Ø)	$y = 0.259+0.647x$	0.18	0.34	0.435*	0.19	0.15	-
(18)	TS-GM(mm)	$y = \bar{0}.032+1.4x$	0.03	0.06	0.987****	0.97	L 0.005	L 0.005
(19)	TS-GM(bØ)	$y = 0.177+0.795x$	0.14	0.20	0.689***	0.49	0.2-0.15	L 0.10
(20)	GM-S(Ø)	$y = \bar{0}.446+3.092x$	0.47	0.93	0.652***	0.425	L 0.025	0.2-0.15
(21)	GM-S(mm)	$y = 0.525-0.585x$	0.20	0.38	$\bar{0}.36$	0.13	L 0.0005	-
(22)	TS-S(Ø)	$y = 0.393+0.173x$	0.17	0.07	0.533*	0.28	L 0.0005	L 0.0005
(23)	TS-S(mm)	$y = 0.506-0.365x$	0.21	0.27	$\bar{0}.319$	0.10	L 0.0005	-

GM = Grain Mount, TS = Thin Section and S = Sieving Techniques.

Table 14 Standard Deviations in Phi Units for Size Distributions of Eighteen Sandstone Samples Analyzed by Grain Mount, Thin Section, and Sieving Techniques

Sample No.	Std. Dev. Grain Mount Obs.	Std. Dev. Thin Section Obs.	Std. Dev. Thin Section Corr.	Std. Dev. Sieve Obs.	Std. Dev. Sieve Corr.
1	0.6106	0.6035	0.6549	0.60	1.4413
2	0.709	0.4977	0.7185	1.74	1.745
3	0.4471	0.6731	0.5491	1.41	0.9358
4	0.3856	0.5624	0.5903	-	0.7466
5	0.5651	0.5557	0.6254	1.28	1.3007
6	0.6514	0.5457	0.6813	1.322	1.5675
7	0.4062	0.6324	0.5226	1.34	0.8094
8	0.3769	0.3940	0.5036	0.612	0.7188
9	0.3789	0.4972	0.5049	0.81	0.725
10	0.3095	0.4115	0.4592	0.315	0.5104
11	0.4461	0.4968	0.5484	0.36	0.9328
12	0.5926	1.1508	0.6432	1.86	1.3857
13	0.5737	0.4449	0.631	2.32	1.3273
14	0.6933	0.6685	0.7084	1.28	1.697
15	0.5267	0.4505	0.6006	0.93	1.1819
16	0.53	0.6068	0.6027	0.97	1.1922
17	0.3939	0.5348	0.5146	0.63	0.7714
18	0.7123	0.9743	0.7207	2.22	1.7558

Table 15 Linear Regression and Correlation Data for Skewness in Phi and Millimeter Units for Size Distributions of Eighteen Sandstone Samples Analyzed by Grain Mount, Thin Section and Sieving Techniques

Equation No.	Technique	Regression Formula (y = a+bx)	Se	Sb	r	r^2	Pb	Pa
(24)	TS-GM(Ø)	y = 0.402+0.766x	0.39	0.23	0.639^{***}	0.41	L 0.15	L 0.005
(25)	TS-GM(mm)	y = $\bar{0}.022+0.998x$	0.44	0.25	0.708^{***}	0.50	M 0.5	M 0.5
(26)	GM-S(Ø)	y = 0.31+0.31x	0.25	0.15	0.460^{*}	0.21	L 0.0005	-
(27)	TS-S(Ø)	y = 0.22+0.325x	0.47	0.18	0.421^{*}	0.18	L 0.005	-
(28)	GM-S(Ø)	y = 0.966+0.862x	0.56	0.34	0.551^{*}	0.304	0.5-0.25	L 0.0005
(29)	TS-S(Ø)	y = 0.279+0.295x	0.47	0.16	0.43^{*}	0.19	L 0.0005	-
(30)	GM-S(mm)	y = 0.837-0.152x	0.39	0.22	$\bar{0}.167$	0.03	L 0.0005	-
(31)	TS-S(mm)	y = 1.06-0.476x	0.59	0.37	$\bar{0}.306$	0.094	L 0.005	-

GM = Grain Mount; TS = Thin Section; S = Sieving Techniques; Values of Sieve Phi Skewness in Equations 26 and 27 are Derived from Inman's "First Skewness Measure" and from "Second Skewness Measure" in Equations 28 and 29.

TABLE 16

Measure of Symmetry (Skewness) in Phi Units for Size Distributions of Eighteen Sandstone Samples Analyzed by Grain Mount, Thin Section, and Sieving Techniques

Sample No.	Grain Mount Observed	Thin Section Observed	Thin Section Corrected	Sieve Observed	Sieve Corrected
1	$\bar{0}.0379$	0.1921	0.3726	0.465	0.9337
2	0.4452	0.6692	0.7429	1.74	1.35
3	0.1969	0.6824	0.5526	1.364	1.136
4	0.0930	0.5655	0.4728	-	1.0465
5	0.3905	1.5103	0.701	1.415	1.303
6	0.8241	0.7912	1.0333	2.218	1.6768
7	0.0682	0.5013	0.4539	1.351	1.025
8	0.7885	0.9228	1.006	0.808	1.6461
9	$\bar{0}.2993$	0.1192	0.1723	1.604	0.7083
10	0.4747	0.8665	0.7655	1.1724	1.3756
11	$\bar{0}.0170$	0.3008	0.3886	$\bar{0}.221$	0.9517
12	0.3386	0.3035	0.6612	1.2989	1.2583
13	$\bar{0}.1014$	0.5150	0.3239	1.0508	0.8789
14	0.3404	1.5261	0.6626	1.6201	1.2598
15	1.2610	0.9809	1.3682	2.1710	2.0535
16	0.0662	$\bar{0}.0480$	0.4524	1.526	1.023
17	$\bar{0}.3187$	$\bar{0}.3121$	0.1574	0.1594	0.6916
18	0.4529	0.9503	0.7488	0.8851	1.3568

Sieve observed = $a_{2\phi}$ (Inman's second measure of skewness)

Table 17 Linear Regression and Correlation Data for Kurtosis in Phi and Millimeter Units for Size Distributions of Eighteen Sandstone Samples Analyzed by Grain Mount, Thin Section and Sieving Techniques.

Equation No.	Technique	Regression Formula (y = a+bx)	Se	Sb	r	r^2	Pb	Pa
(32)	TS-GM(Ø)	y = 3.839+0.075x	1.43	0.36	0.052	0.003	-	-
(33)	TS-GM(mm)	y = 2.1+0.62x	2.17	0.33	0.442*	0.19	L 0.15	L 0.10
(34)	GM-S(Ø)	y = 0.838+0.254x	0.39	0.09	0.553**	0.31	L 0.0005	-
(35)	GM-S(mm)	y = 1.58+0.122x	0.25	0.04	0.649***	0.42	L 0.025	-
(36)	TS-S(Ø)	y = 4.84-0.423x	1.45	0.81	$\bar{0}$.134	0.02	L 0.25	-
(37)	TS-S(mm)	y = 2.83+0.858x	2.4	1.92	0.114	0.01	0.25-0.20	

GM = Grain Mount; TS = Thin Section and S = Sieving Technique

TABLE 18

Measure of Peakedness (Kurtosis) in Phi Units for Size Distributions of Eighteen Sandstone Samples Analyzed by Grain Mount, Thin Section, and Sieving Techniques

Sample No.	Grain Mount Observed	Thin Section Observed	Sieving Observed
1	2.7383	3.0534	1.270
2	2.7707	3.5573	2.120
3	2.5764	3.9536	1.550
4	3.5967	3.3063	–
5	2.5532	8.0940	1.435
6	4.3609	3.8407	2.740
7	3.0150	2.7761	1.620
8	4.8357	4.4049	1.840
9	4.4296	3.6320	2.210
10	4.1901	4.8051	1.390
11	2.9354	3.4667	1.520
12	1.9771	1.9667	1.660
13	3.4374	5.6007	1.620
14	2.1729	5.9084	1.494
15	5.3487	4.4790	2.170
16	2.8464	2.8934	1.810
17	2.7635	3.8430	1.020
18	2.8690	3.9926	0.953

Table 19 Mean Size Parameters in Phi Units for Size Distributions of Four Sandstone Samples Analyzed by Grain Mount, Thin Section, and Sieving Techniques

Sample No.	Technique	Mean/ Median	Standard Deviation	Skewness	Kurtosis	Clay and or Matrix
2	Sieving	2.340	1.740	0.670	1.191	
	Thin Section	1.930	0.498	0.669	3.557	20 percent
	Grain Mount	1.863	0.709	0.445	2.771	
8	Sieving	3.550	0.612	0.298	1.675	
	Thin Section	3.502	0.394	0.923	4.405	11.5 percent
	Grain Mount	3.213	0.377	0.788	4.836	
11	Sieving	2.870	0.360	$\bar{0}.162$	1.182	
	Thin Section	2.898	0.497	0.301	3.467	3 percent
	Grain Mount	2.346	0.446	$\bar{0}.017$	2.935	
18	Sieving	1.375	2.220	0.317	0.864	-
	Thin Section	0.304	0.974	0.950	3.993	
	Grain Mount	0.257	0.712	0.453	2.869	

Table 20 Linear Regression and Correlation Data for Interrelation among Size Parameters in Phi and Millimeter Units of Eighteen Sandstone Samples Analyzed by Grain Mount Technique

Equation No.	Technique	Regression Formula (y = a+bx)	Se	Sb	r	r^2	Pb
(38)	S-M(Ø)	$y = 0.802-0.124x$	0.10	0.04	$\bar{0}.627^{***}$	0.39	L 0.005
(39)	S-M(mm)	$y = \bar{0}.023+0.472x$	0.01	0.02	0.994^{****}	0.987	L 0.005
(40)	SK-M(Ø)	$y = 0.658-0.167x$	0.40	0.15	$\bar{0}.267$	0.07	L 0.0005
(41)	K-M(Ø)	$y = 2.45+0.369x$	0.95	0.35	0.251	0.06	L 0.05
(42)	SK-S(Ø)	$y = \bar{0}.147+0.818x$	0.40	0.76	0.259	0.07	M 0.25
(43)	GMs-SSK(Ø)	$y = 0.136+0.37x$	0.20	0.05	0.70^{***}	0.49	L 0.0005
(44)	K-S(Ø)	$y = 4.83-2.95x$	0.90	1.70	0.398^{*}	0.158	L 0.025
(45)	SK-K(Ø)	$y = \bar{1}.55+0.504x$	0.17	0.06	0.944^{****}	0.89	L 0.0005
(46)	SK-K(Ø)	$y = 0.855-0.259x$	0.12	0.05	$\bar{0}.849^{****}$	0.72	L 0.0005

S = Standard Deviation; M = Mean; SK = Skewness; K = Kurtosis; GMs = Standard Deviation Grain Mount and SSK = Sieve Phi Skewness.

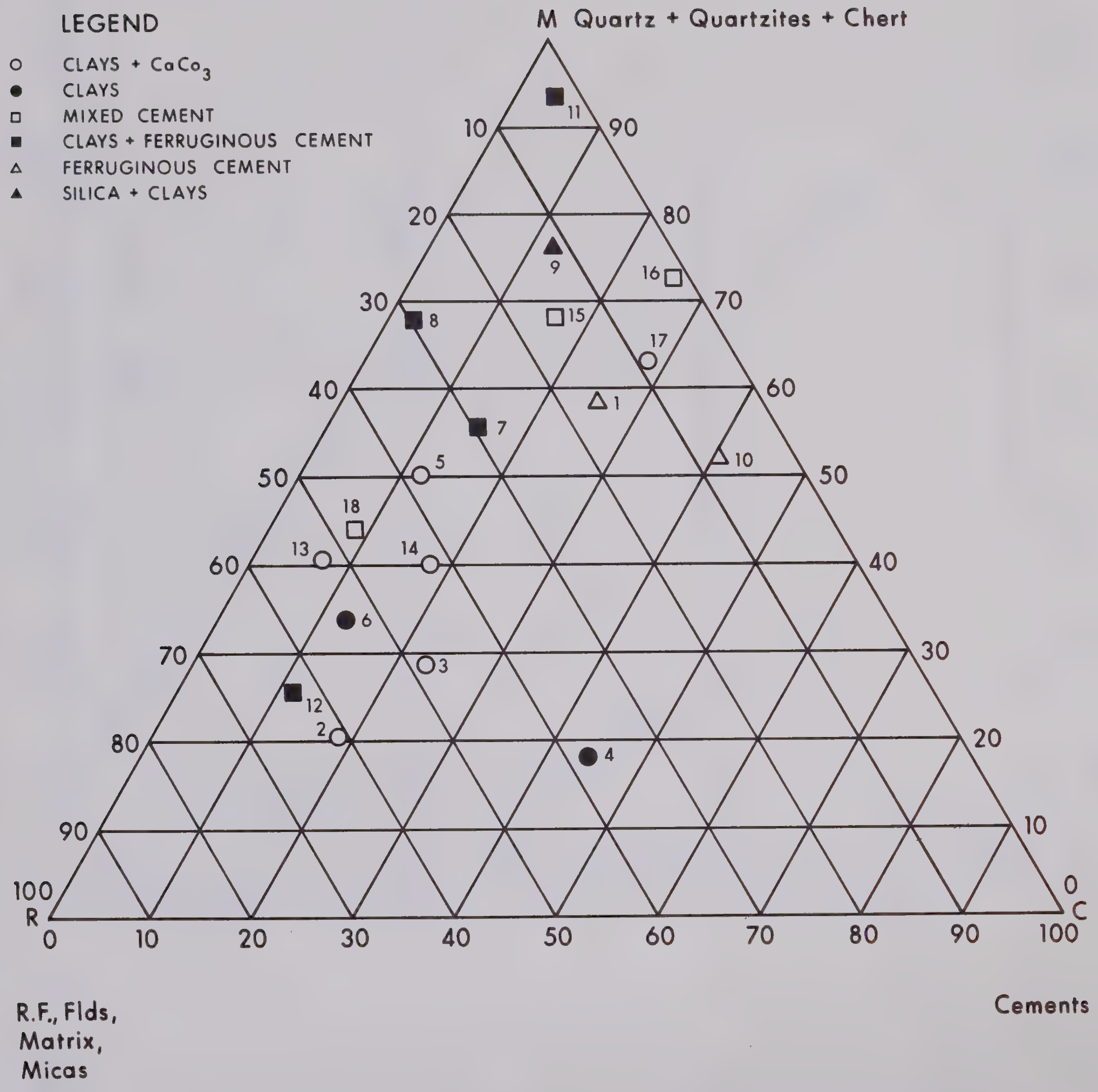

Fig. 1 MINERAL COMPOSITION OF EIGHTEEN SAMPLES OF ARKOSE, LITHIC, SUBQUARTZOSE AND QUARTZOSE SANDSTONES PLOTTED ON MRC-TERNARY DIAGRAM.

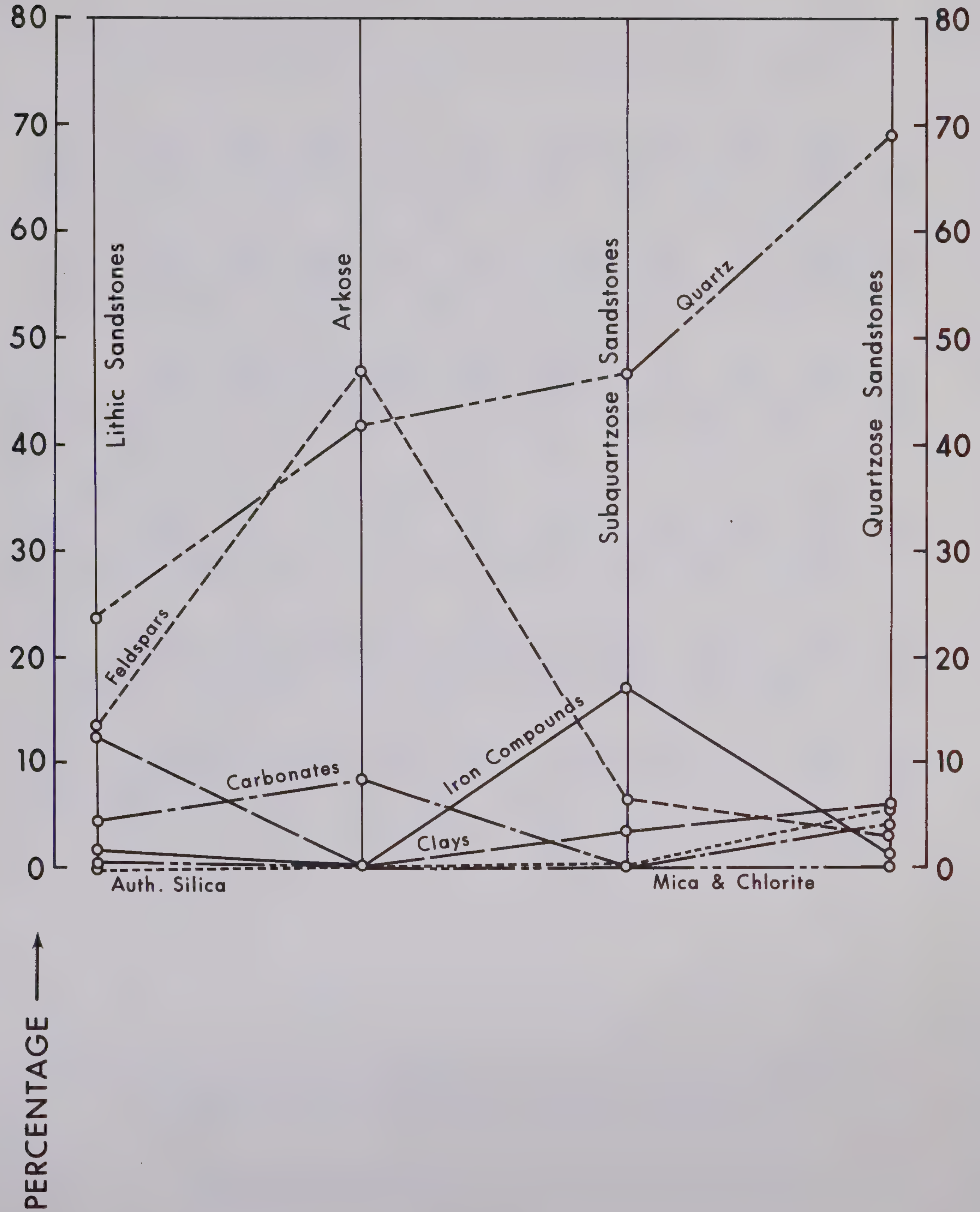

Fig. 2 AVERAGE MINERAL COMPOSITION OF (DETRITAL AND CHEMICAL CONSTITUENTS) EIGHTEEN SAMPLES OF ARKOSE, LITHIC, SUBQUARTZOSE, AND QUARTZOSE SANDSTONES.

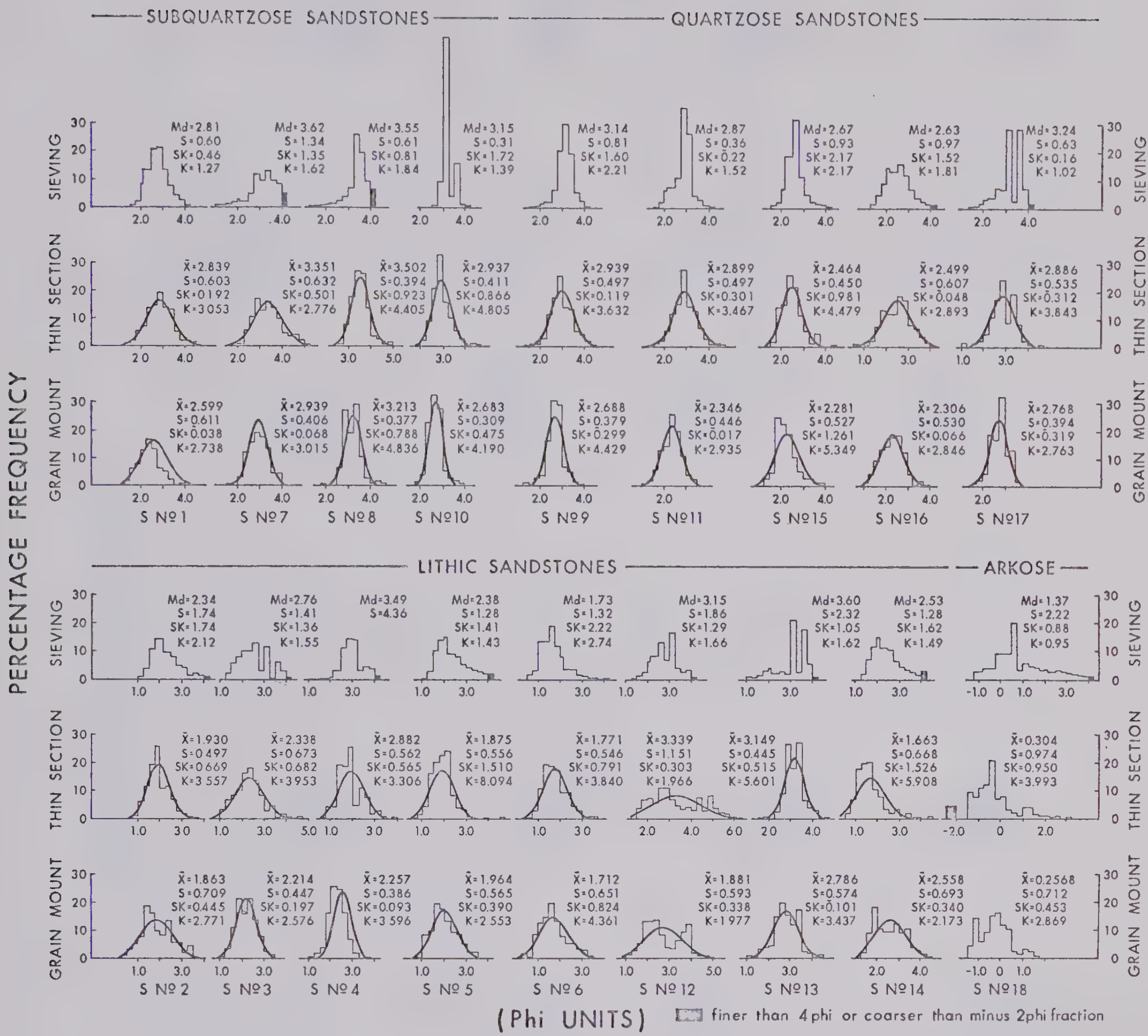

FIG. 3 SIZE DISTRIBUTION AND EXPECTED FREQUENCY CURVES OF EIGHTEEN SANDSTONE SAMPLES ANALYZED BY GRAIN MOUNT, THIN SECTION AND SIEVING TECHNIQUES

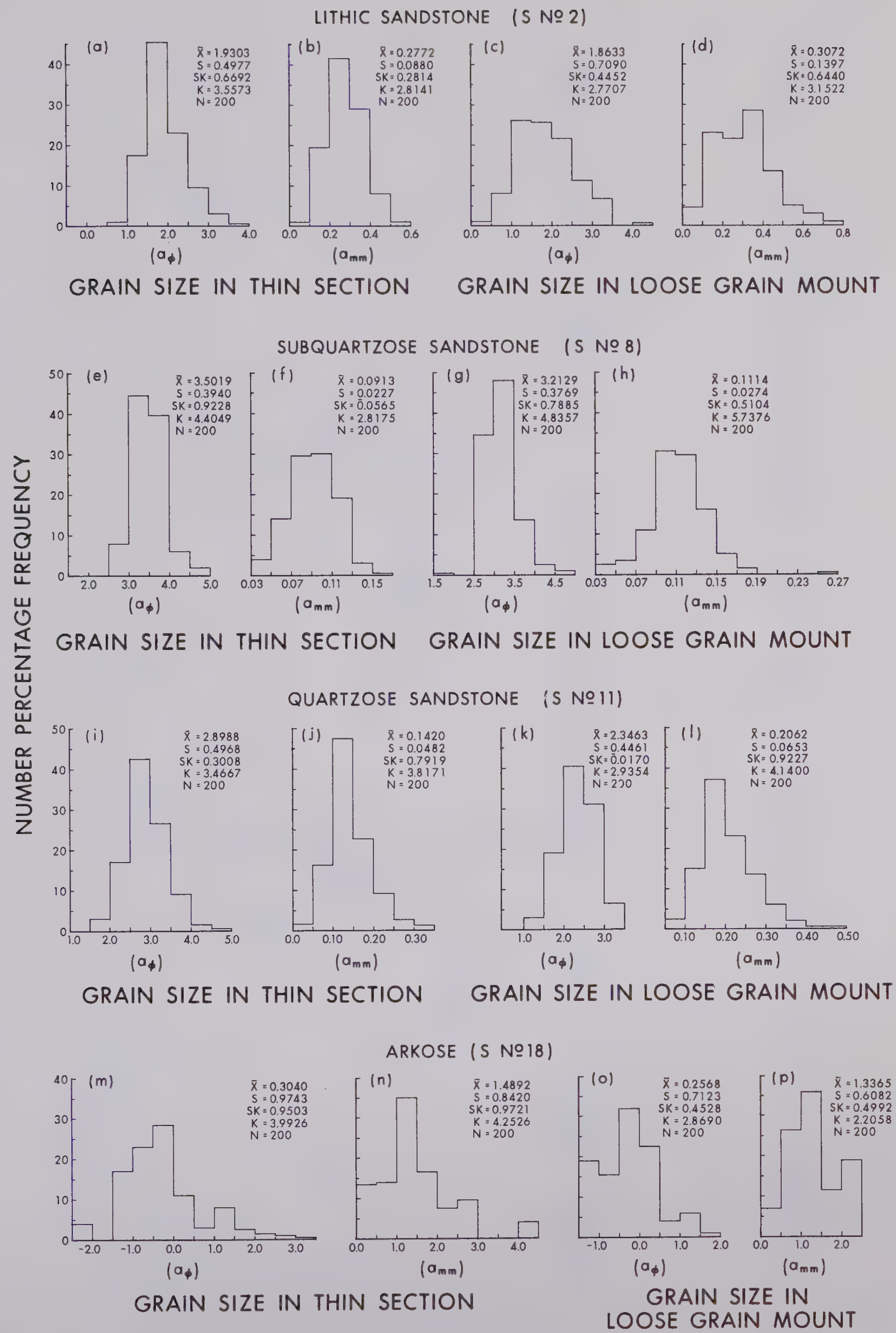

Fig. 4 SIZE FREQUENCY HISTOGRAMS OF FOUR SANDSTONE SAMPLES IN THIN SECTION AND LOOSE GRAIN MOUNT TECHNIQUES FOR PHI AND MILLIMETER DATA.

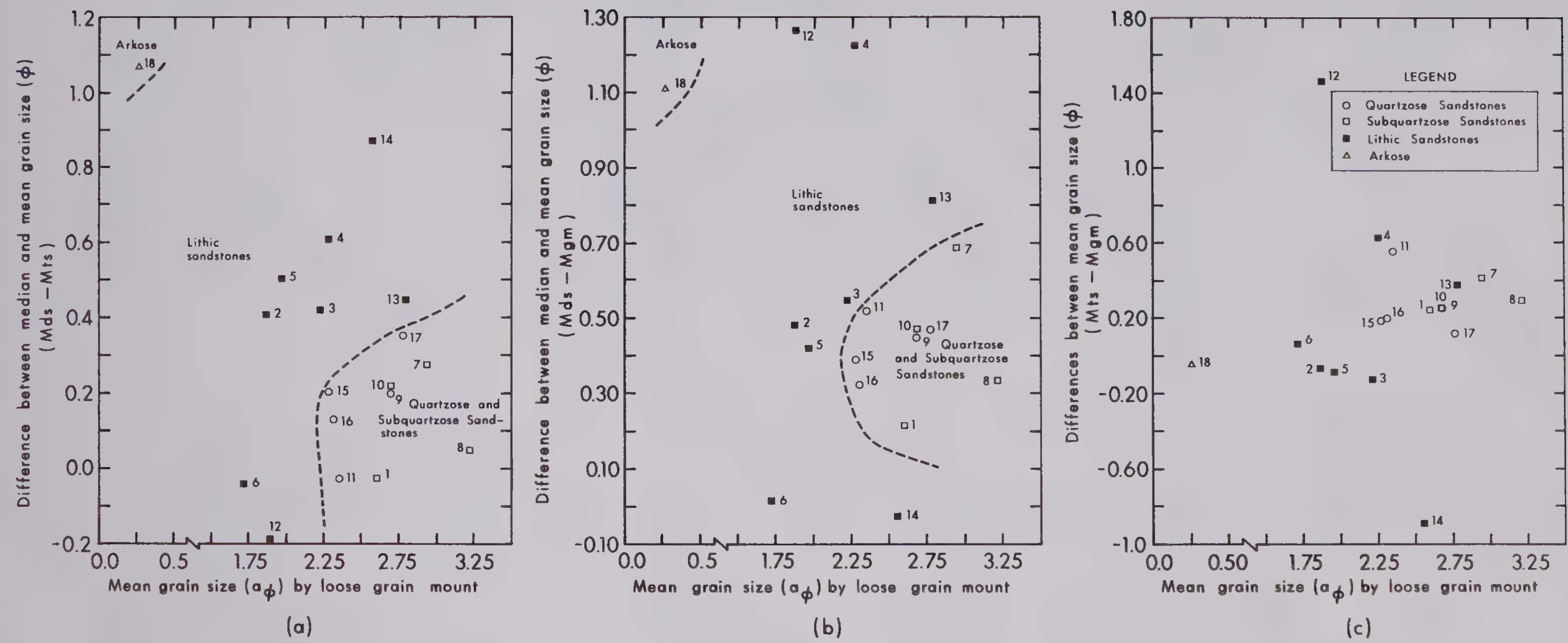

Fig. 5 SCATTER DIAGRAMS SHOWING RELATIONSHIPS AMONG DIFFERENCES IN GRAIN SIZE VALUES OBTAINED BY LOOSE GRAIN MOUNT, THIN SECTION AND SIEVING TECHNIQUES.

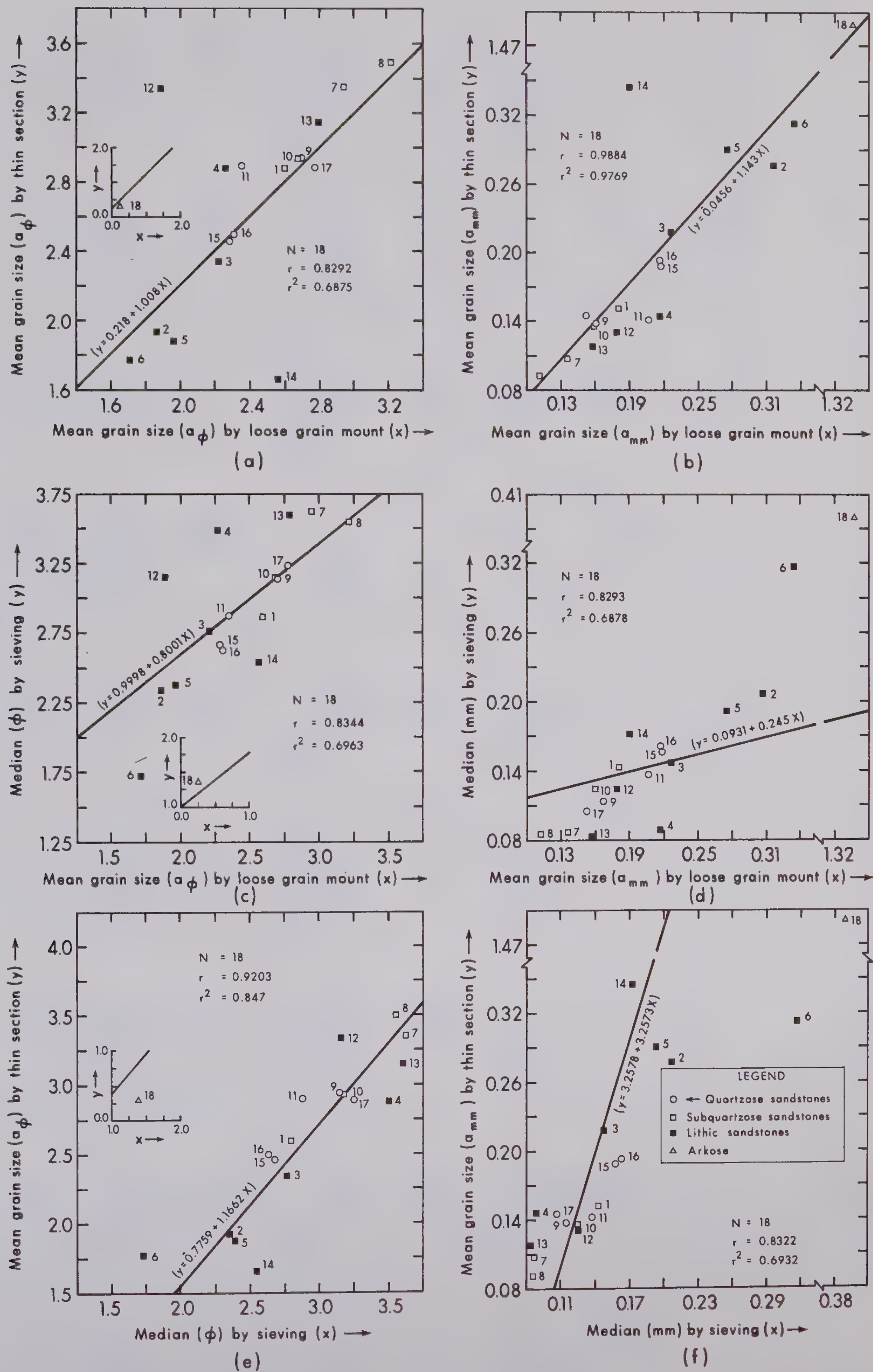

Fig. 6 REGRESSION LINES OF MEANS FOR SIZE DISTRIBUTIONS OF EIGHTEEN SANDSTONE SAMPLES ANALYZED BY LOOSE GRAIN MOUNT, THIN SECTION, AND SIEVING TECHNIQUES.

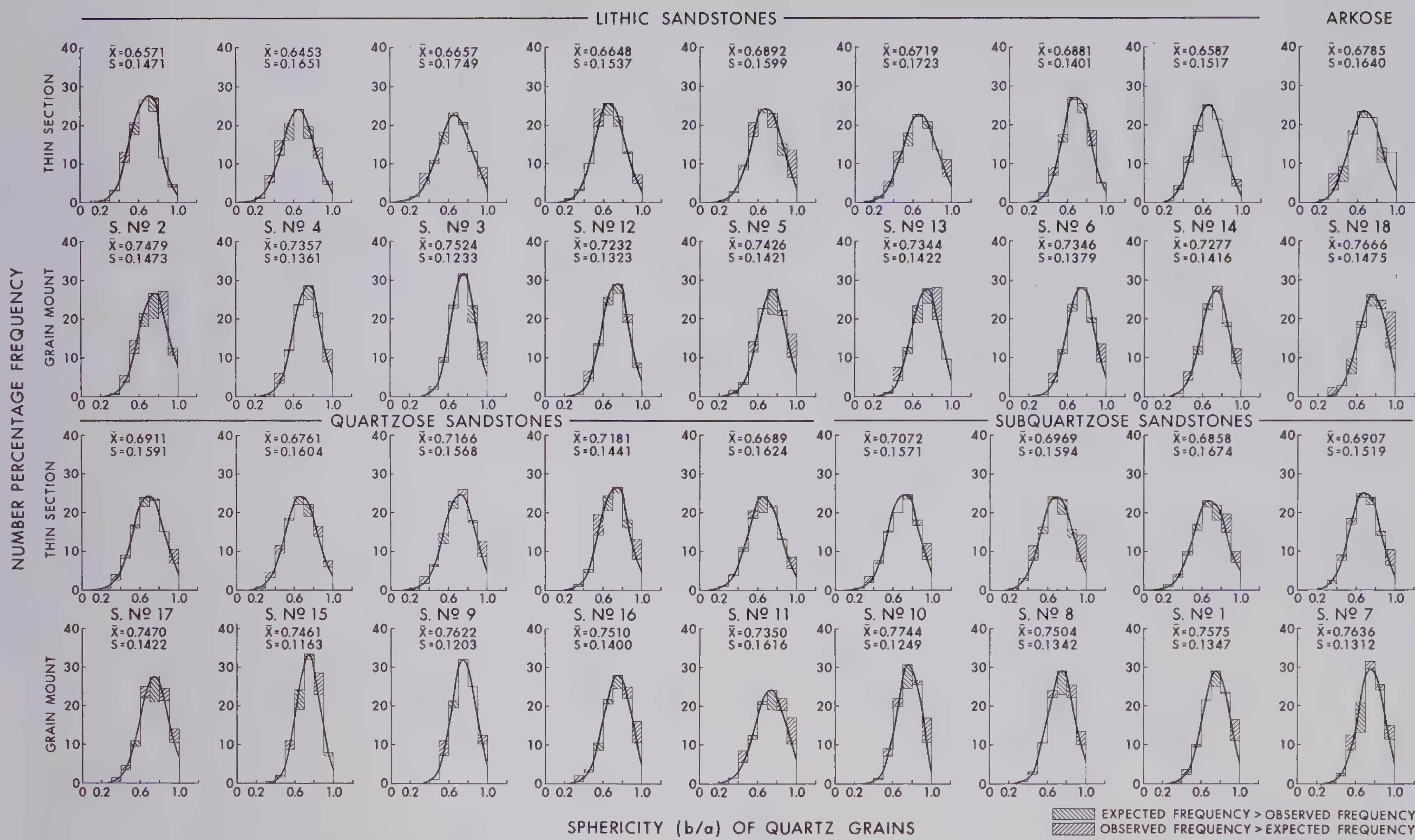

FIGURE 7 SPHERICITY FREQUENCY HISTOGRAMS OF QUARTZ GRAINS BY THIN SECTION AND LOOSE GRAIN MOUNT TECHNIQUES

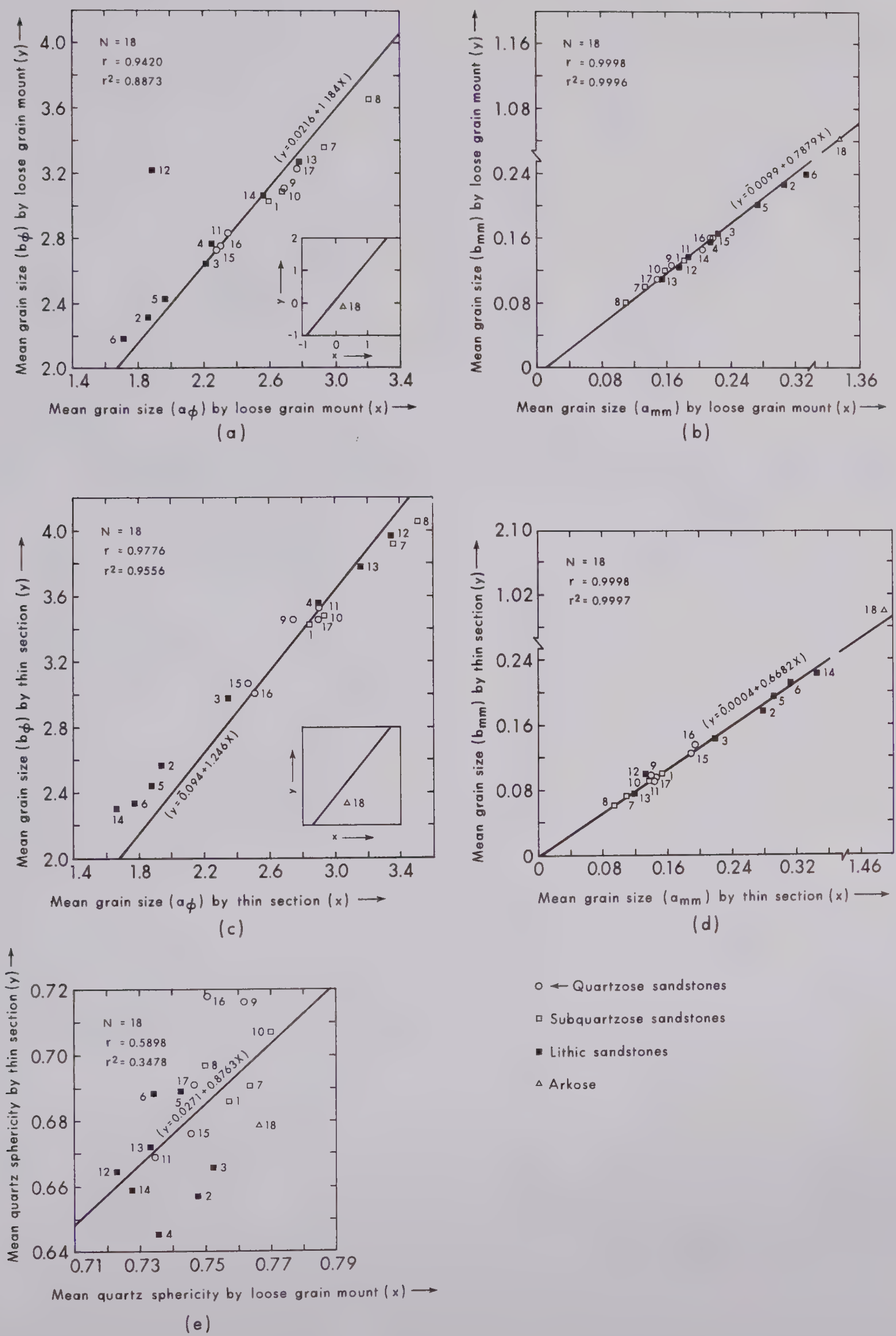

Fig. 8 REGRESSION LINES OF a-axes ON b-axes AND MEAN SPHERICITY (b/a) OF QUARTZ GRAINS FOR SIZE DISTRIBUTIONS OF EIGHTEEN SANDSTONE SAMPLES ANALYZED BY LOOSE GRAIN MOUNT AND THIN SECTION TECHNIQUES.

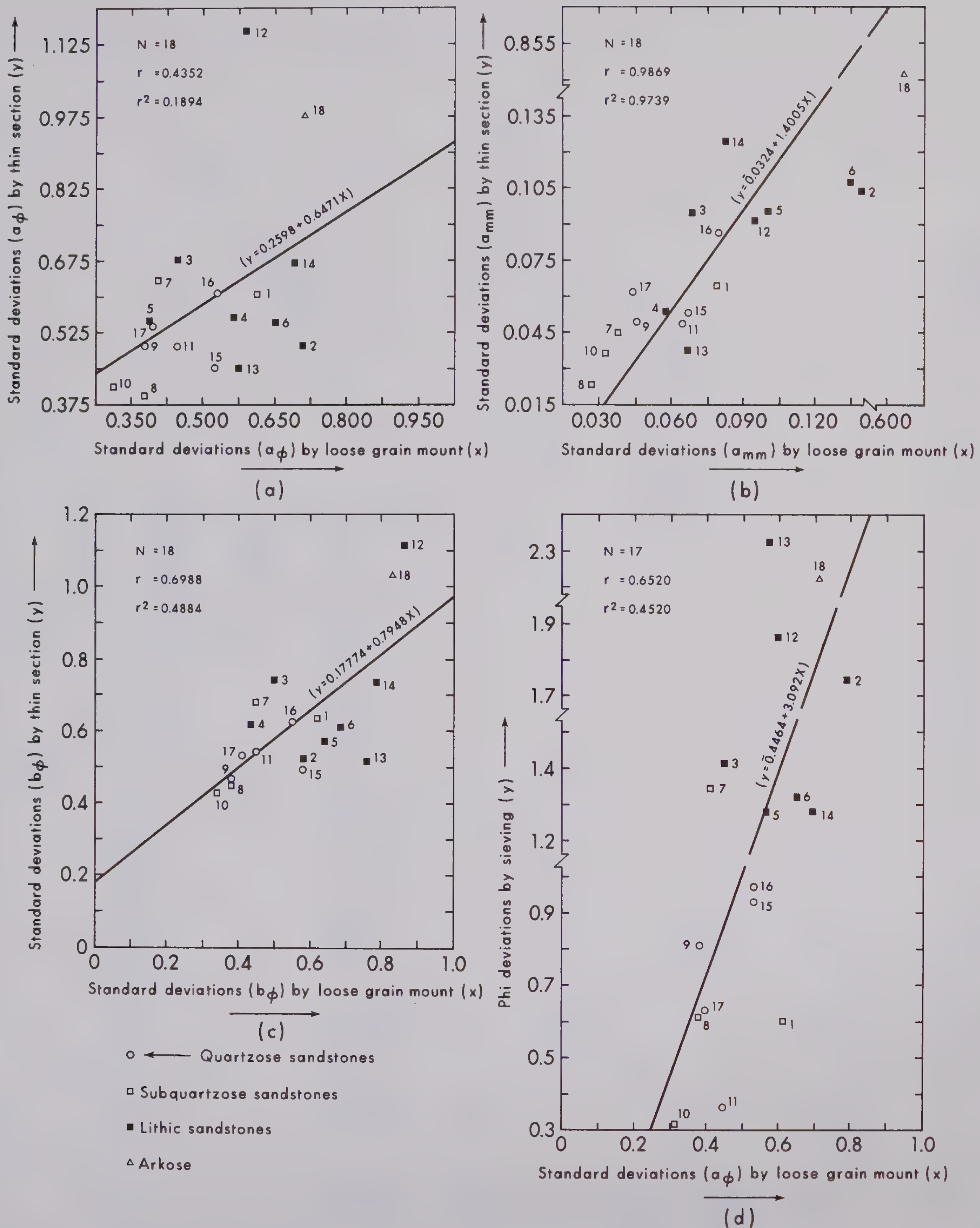

Fig. 9 REGRESSION LINES OF STANDARD DEVIATIONS FOR SIZE DISTRIBUTIONS OF EIGHTEEN SANDSTONE SAMPLES ANALYZED BY LOOSE GRAIN MOUNT, THIN SECTION AND SIEVING TECHNIQUES.

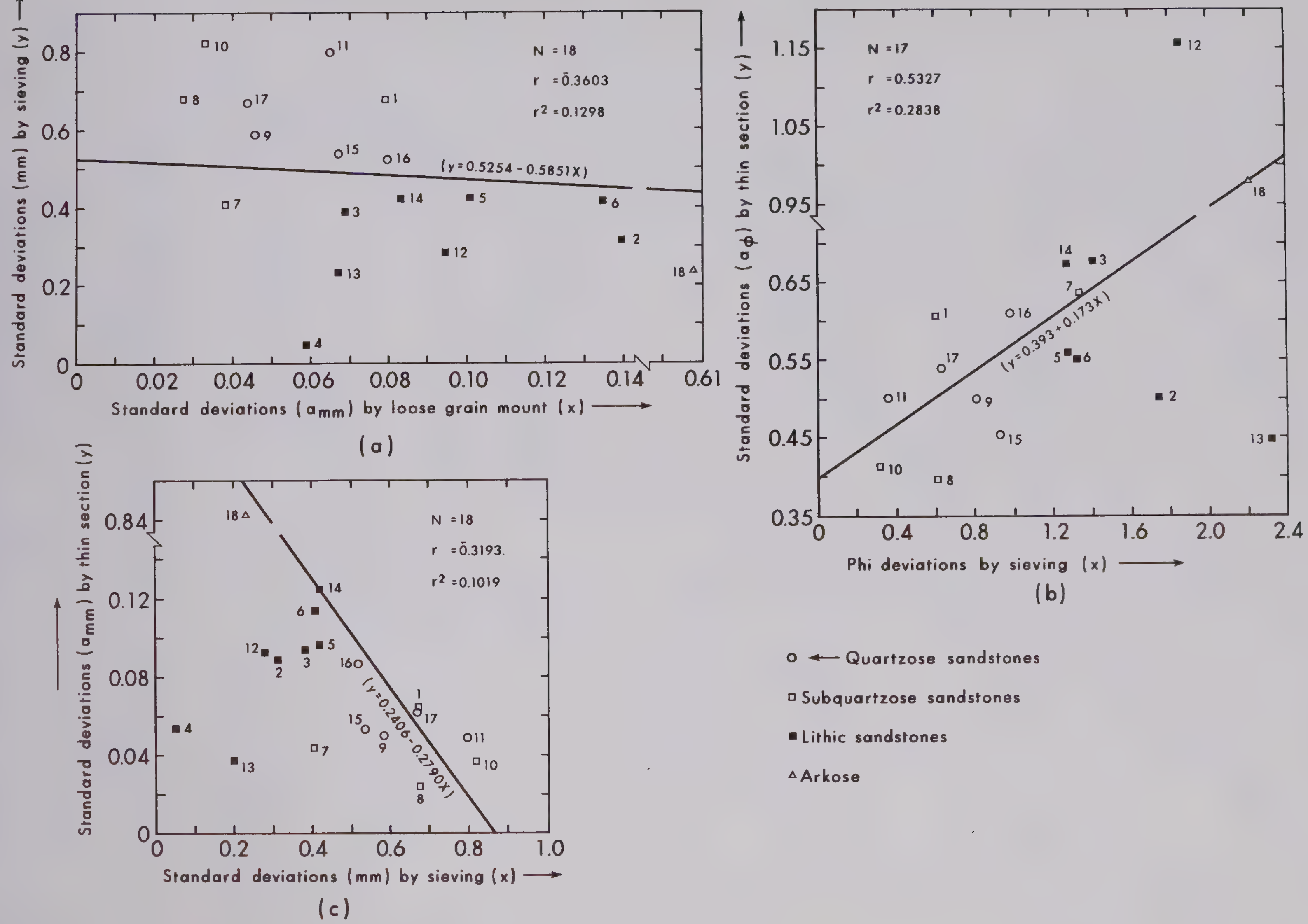

Fig. 10 REGRESSION LINES OF STANDARD DEVIATIONS FOR SIZE DISTRIBUTIONS OF EIGHTEEN SANDSTONE SAMPLES ANALYZED BY LOOSE GRAIN MOUNT, THIN SECTION AND SIEVING TECHNIQUES.

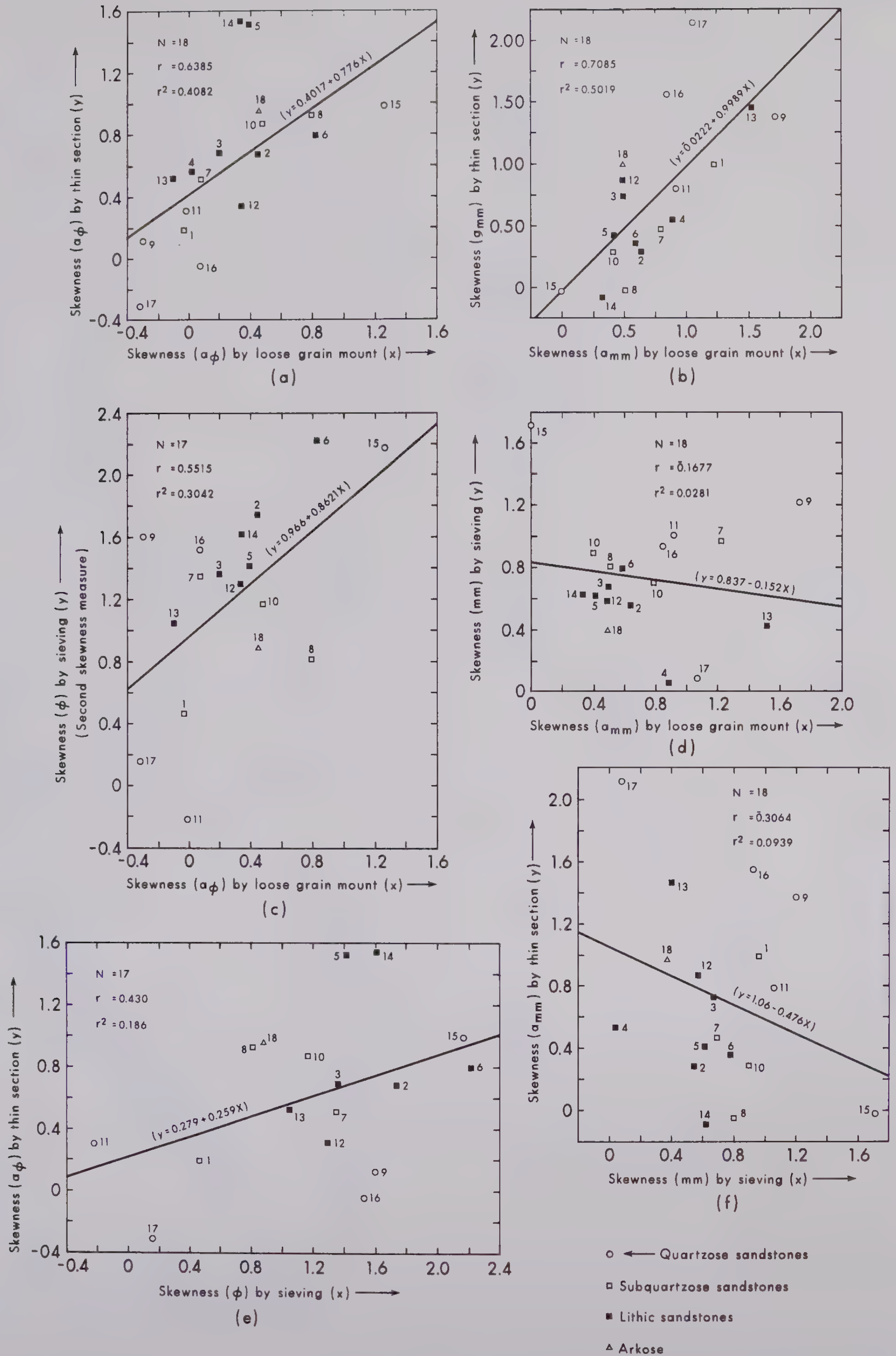

Fig. 11 REGRESSION LINES OF SKEWNESS VALUES FOR SIZE DISTRIBUTIONS OF EIGHTEEN SANDSTONE SAMPLES ANALYZED BY LOOSE GRAIN MOUNT, THIN SECTION AND SIEVING TECHNIQUES.

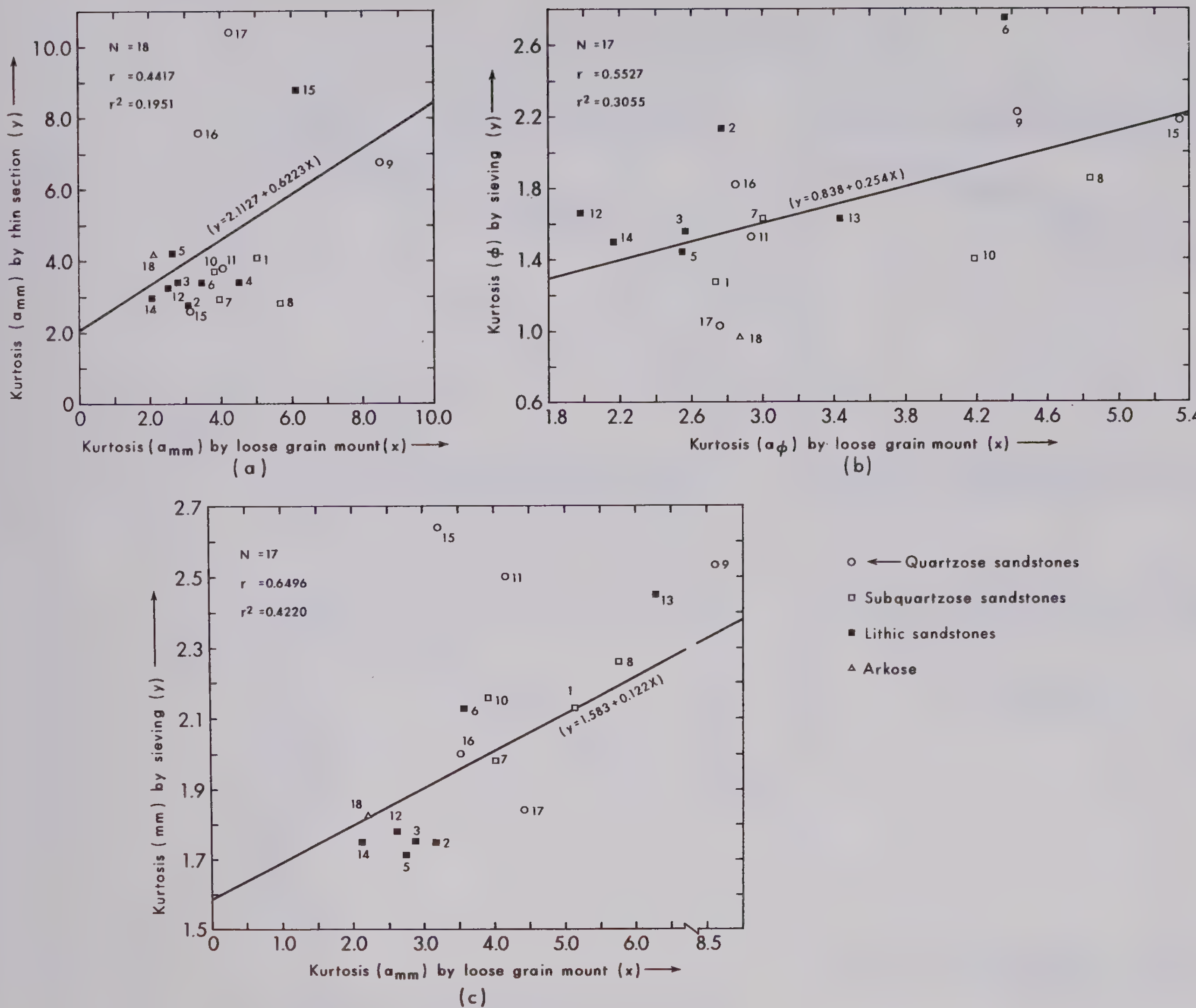

Fig. 12 REGRESSION LINES OF KURTOSIS VALUES FOR SIZE DISTRIBUTIONS OF EIGHTEEN SANDSTONE SAMPLES ANALYZED BY LOOSE GRAIN MOUNT, THIN SECTION AND SIEVING TECHNIQUES.

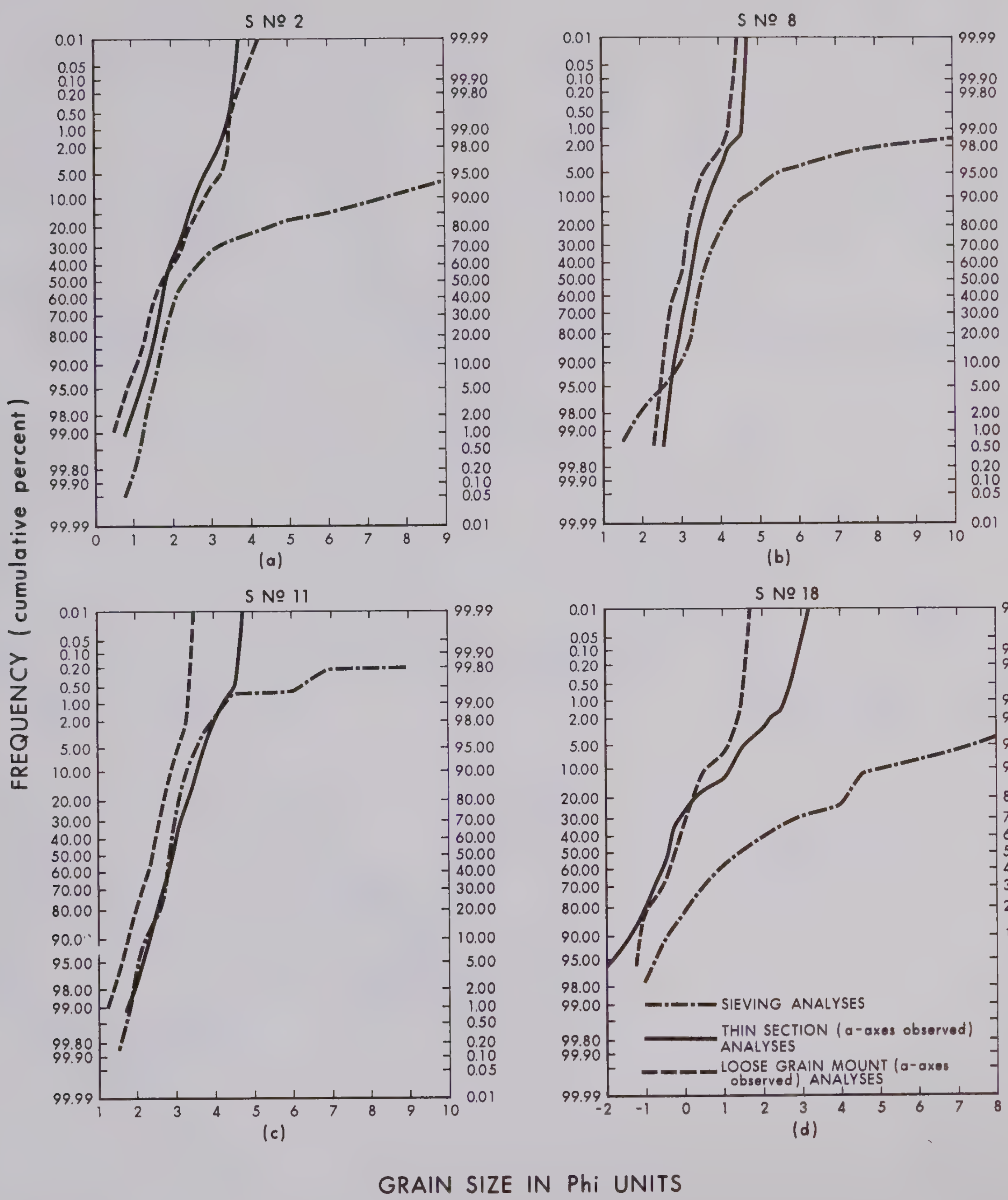

Fig. 13 CUMULATIVE FREQUENCY CURVES OF FOUR SANDSTONE SAMPLES OBTAINED BY LOOSE GRAIN MOUNT, THIN SECTION AND SIEVING TECHNIQUES.

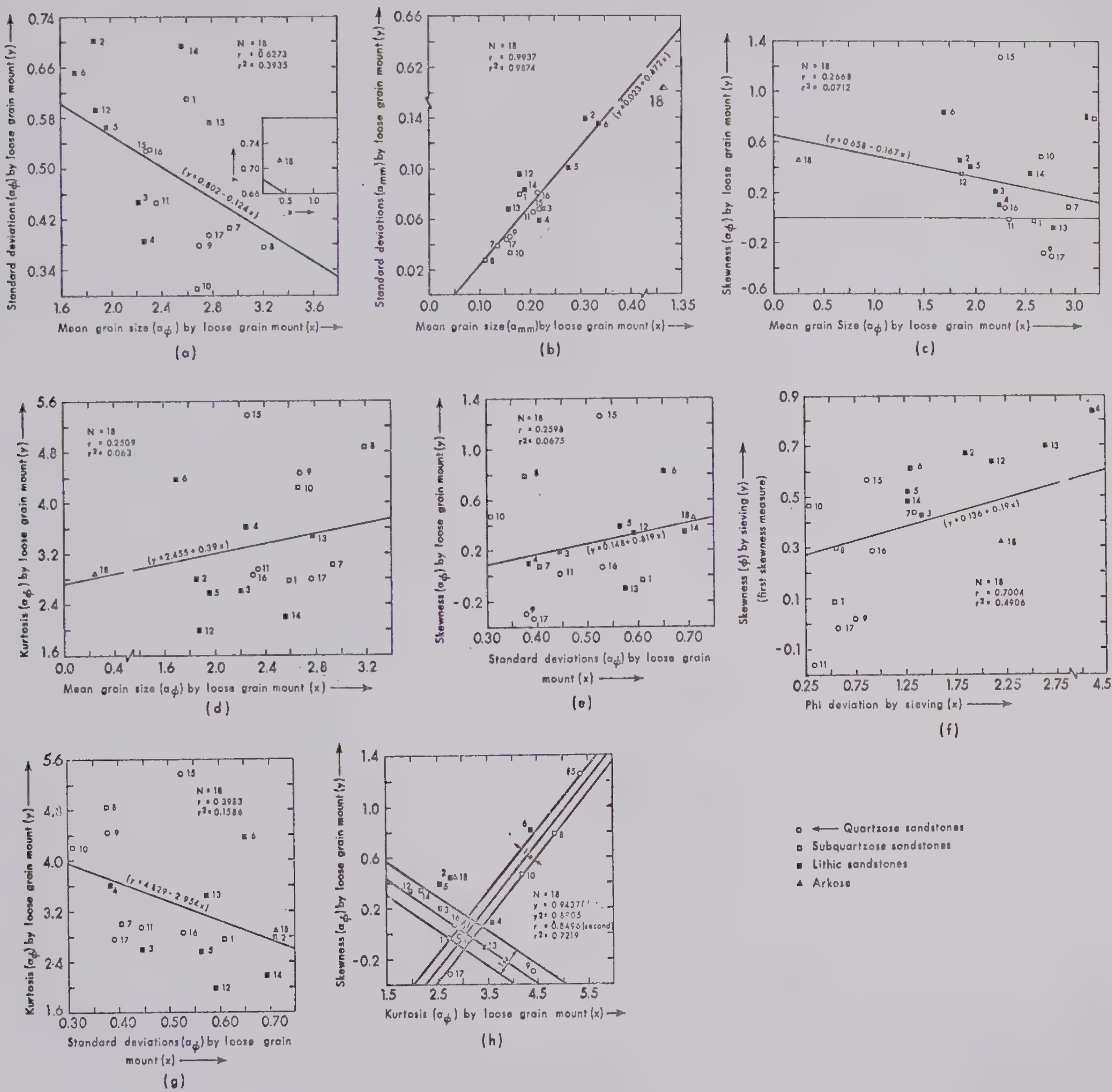

Fig. 14 REGRESSION LINES SHOWING INTERRELATION AMONG SIZE PARAMETERS FOR SIZE DISTRIBUTIONS OF EIGHTEEN SANDSTONE SAMPLES ANALYZED BY GRAIN MOUNT AND SIEVING TECHNIQUES.